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RESEARCH AND DEVELOPMENT STRATEGIES FOR HUMAN CENTERED AND GROUP SUPPORT TECHNOLOGIES

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The Armstrong Laboratory's Acquisition Logistics Research and Development Activity at Wright Patterson Air Force Base, Ohio, is actively investigating both human centered technology and group support technology. In order to ensure the development of these technologies with a focus on customer needs and the use of relevant technological developments, the laboratory has been involved in a strategic planning process for future R&D activities. This paper reports the results of research performed by an Institute for Defense Analyses study team whose immediate goal was to help refine and sharpen the focus of the Acquisition Logistics R&D Activity's strategy for human centered technology and group support technology by providing information about, and analysis of, potential customers, relevant technological developments, and probable alternative strategies.

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PREFACE

This paper is the result of work performed by the Institute for Defense Analyses (IDA) under contract number MDA 903 89 C 0003, task order T-D6-554, Measurement Issues in Unified Life Cycle Engineering. This work was performed for the Air Force Armstrong Laboratory, Human Resources Division, Special Project Office and the Under Secretary of Defense for Acquisition [USD(A)], Research and Advanced Technology, Office of Engineering Technology.

This paper specifically addresses the development and refinement of a strategy for Human Centered Technology (HCT) and Group Support Technology (GST) Research and Development (R&D) by developing information about potential military customers and pertinent technology developments. In writing this report, the authors recognized that in this rapidly changing Defense Department and global environment, information on potential customers in the military obtained over a period of a year might change from one month to the next. The authors have attempted to note the changes; however, the reader is advised that the customer information is a snapshot of the situation roughly in the autumn of 1991.[1]

This paper was reviewed by Dr. Fred Riddell and Dr. Paul Richanbach, both of IDA's Strategy, Forces, and Resources Division (SFRD), and Tom Bahan [formerly of Air Force Logistics Command (AFLC/LF)], an IDA consultant.

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[1] For example, a reviewer informed us that the creation of the Joint Logistics Systems Center (JLSC) in January 1992 will have a tremendous impact on the R&D activities of potential customers.

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Ed Boyle at the Armstrong Laboratory, Human Resources Division, Logistics Research Branch, was extremely helpful in supplying information on human-centered technologies and the Logistics Support Analysis/Logistics Support Analysis Record (LSA/LSAR) process and in arranging the discussion meetings held at WPAFB.

The authors also wish to thank Dr. Burke Burright for his continued support and suggestions and supply of information on new enabling technologies.

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GLOSSARY

A3I	Army-NASA Aircrew/Aircraft Integration
ACALS	Army CALS
ACI	Analytical Condition Inspection
ACM	Advanced Cruise Missile
ADCARS	Engineering Data Computer Assisted Retrieval System
ADP	Automated Data Processing
AF	Air Force
AFAM	Air Force Acquisition Model
AFB	Air Force Base
AFCC	Air Force Communications Command
AFEMS	Air Force Equipment Management System
AFIF	Air Force Industrial Fund
AFLC	Air Force Logistics Command
AFMC	Air Force Materiel Command
AFSC	Air Force Systems Command
AFTOMS	Air Force Technical Order Management System
AIRT	Automation Impacts Research Testbed
ALC	Air Logistics Center
ALD	Acquisition Logistics Division
AM	Acquisition Model
ASD	Aeronautical Systems Division
ATIS	A Tool Integration Standard
ATOS	Automated Technical Order System
C^2	Command and Control
CAD	Computer-Aided Design
CADD	Computer-Aided Design and Drafting
CAE	Computer-Aided Engineering
CALS	Computer-Aided Acquisition and Logistics Support
CAM	Computer-Aided Manufacturing

CAPP	Computer-Aided Design and Drafting
CAR	Crewstation Assessment of Reach
CASHE	Computer-Aided System Human Engineering
CAT	Cockpit Automation Technology
CCSS	Commodity Command Standard System
CD/ROM	Compact Disk/Read Only Memory
CDMS	Contracting Data Management System
CDR	Critical Design Review
CE	Concurrent Engineering
CIM	Computer-Integrated Manufacturing
CIM	Corporate Information Management
CIP	Component Improvement Program
CITIS	Contractor Integrated Technical Information System
COMBIMAN	COMputerized BIomechanical MAN-Model
CPAS	Central Procurement Accounting System
CPU	Central Processing Unit
CRDA	Cooperative Research and Development Agreement
CSTI	Center for Supportability and Technology Inertion
CSTI	Center for Supportability and Technology Insertion
CUI	Common User Interface
DARPA	Defense Advanced Research Projects Agency
DASD	Deputy Assistant Secretary of Defense
DDN	Defense Data Network
DDR&E	Director, Defense Research and Engineering
DEC	Digital Equipment Corporation
DEPTH	Design Evaluation for Personnel, Training, and Human Factors
DFT	Depot Field Team
DICE	DARPA Initiative in Concurrent Engineering
DLA	Defense Logistics Agency
DMAWG	Depot Maintenance Activation Working Group
DMMIS	Depot Maintenance Management Information Systems
DMR	Defense Management Review
DMRD	Defense Management Report Decision
DO	Operations
DoD	Department of Defense

DoDD	Department of Defense Directive
DoDI	Department of Defense Instruction
DSREDS	Digital Storage and Retrieval Engineering Data Systems
DTA	Decision Tree Analysis
EDMICS	Engineering Data Management Information Control System
EMD	Engineering and Manufacturing Development
EMS	Electronic Meeting System
EN	Engineering
EPD	Engineering Project Description
ETADS	Enhanced Transportation Automated Data system
FACTS	Fast Access to Computerized Time Standards
FMEA	Failure Modes and Effects Analysis
FMECA	Failure Modes Effects and Criticality Analysis
FMS	Flexible Manufacturing Systems
FRC	Flexible Repair Center
FY	Fiscal Year
GD	General Dynamics
GDSS	Group Decision Support System
GOSIP	Government Open System Interconnection Profile
GSS	Group Support System
GST	Group Support Technology
HAZMAT	Hazardous Materials
HCT	Human Centered Technology
HFE	Human Factors Engineering
HITI	Human Issues in Technology Implementation
HOS	Human Operator Simulator
HOSTNET	Host-to-Host Network
HPPM	Human Performance Process Models
HSD	Human Systems Division
IDA	Institute for Defense Analyses
IGES	International Graphics Exchange Standard
ILS	Integrated Logistics Support
ILSWG	Integrated Logistics Support Working Group
IM	Item Manager
IMS	Integrated Management Systems

IPD	Integrated Product Development
IPPD	Integrated Process Planning System
IRM	Information Resource Management
ISG	Intersite Gateway
IWSM	Integrated Weapon System Management
JCALS	Joint Service CALS
JUSTIS	Joint Uniformed Services Technical Information
LAN	Local Area Net
LG	Logistics
LMS	Logistics Systems
LOC	Logistics Operations Center
LSA	Logistics Support Analysis
LSAR	Logistics Support Analysis Record
LSG	Logistics Steering Group
LSOC	Logistical Systems Operations Centers
MAJCOM	Major Command
MANTECH	Manufacturing Technology
MANTECH	Manufacturing Technology
MBPS	Megabits per Second
MCP	Military Construction Program
MDC	Maintenance Data Collection
MISTR	Management of Items Subject to Repair
MONET	Meeting On the NETwork
MPT	Manpower, Personnel, and Training
MPTS	Manpower, Personnel, Training, and Safety
MRP	Manufacturing Resource Planning
MTTR	Mean Time to Repair
NASA	National Aeronautics and Space Administration
NC	Numerical Control
NIST	National Institute for Standards and Technology
OASIS	Operability Assessment System for Integrated Simultaneous Engineering
OC-ALC	Oklahoma City Air Logistics Center
ORTA	Office of Research and Technology Applications
OSHA	Occupational Safety and Hazards Act

OSI	Open Systems Interconnection
OTTD	Ohio Technology Transfer Organization
OTTO	Ohio Technology Transfer Organization
PARC	Palo Alto Research Center
PC	Personal Computer
PC	Personal Computer
PDDB	Product Definition Data Base
PDES	Product Data Exchange using STEP
PDR	Preliminary Design Review
PDT	Product Development Team
PEO	Program Executive Office
PIT	Program Integration Team
PM	Program Manager
PMD	Program Management Document
PMTD	Program Management Transfer Document
POSIX	Operating System Interface
PRDB	Product Development Review Board
R&D	Research and Development
R&M	Reliability and Maintainability
RAMCAD	Reliability, Availability, and Maintainability in Computer-Aided Design
RDB	Requirements Data Bank
REMIS	Reliability and Maintainability Information Systems
REPTECH	Repair Technology
RM&S	Reliability, Maintainability and Supportability
RM&S	Reliability, Maintainability, and Supportability
S&T	Science and Technology
SAE	System Acquisition Executives
SAF/AQ	Secretary of the Air Force (Acquisition)
SAMMIE	Systems for Aiding Man-Machine Interaction Evaluation
SAWS	Supportability Analysis WorkStation
SBIR	Small Business Investigative Research
SC	Communications and Computer Systems
SC&D	Stock Control and Distribution
SE	Support Equipment

SG	Surgeon General
SGML	Standard Generalized Markup Language
SM	System Manager
SNA	System Network Architecture
SOR	Source of Repair
SOW	Statement of Work
SPC	Statistical Process Control
SPM	System Program Manager
SPO	System Project Office
SQL	Structured Query Language
S&T	Science and Technology
STEP	International Standard for the Exchange of Product Data
TAP	Technology Assistance Panel
TCP/IP	Transmission Control Protocol/Internet Protocol
TCTO	Time Critical Technical Order
TEO	Technology Executive Officer
TM	Technical Manual
TO	Technical Order
TOE	Target Operating Environment
TPDC	Training and Performance Data Center
TQM	Total Quality Management
TRC	Technical Repair Center
TRCP	Technical Requirements Control Point
TS	Time Standard
WBS	Work Breakdown Structure
WPAFB	Wright Patterson Air Force Base
WRDC	Wright Research and Development Center
WSMIS	Weapon Systems Management Information System
XP	Plans and Programs
XR	Requirements

EXECUTIVE SUMMARY

Because of the changing environment in the Department of Defense (DoD), future weapon system research and development (R&D) and production will take place in a very different environment than that which has existed since World War II. The DoD budget has been declining since the mid-1980s, and with the end of the Cold War and the attendant change in threat, this trend is likely to continue in this decade. The Administration's acquisition approach for the 1990s is to scale back on production and protect R&D. The U.S. defense budget priorities for FY92/93 include people, technological advantage, efficient acquisition, and streamlined infrastructure. "DoD will continue to initiate and implement fundamental changes in the way it conducts its business . . . . The underlying philosophy is to centralize policies, procedures, standards and systems while decentralizing their execution and implementation."[1]

While these changing priorities will affect how the defense industry does business, so too will today's competitive global market affect how the commercial industry does business. In the commercial sector, competition from abroad has heightened concern for quality and increased the need for reducing risk, development cycle time, and, ultimately, cost. This new approach is reflected in the Total Quality Management (TQM) style of doing business. In the defense sector, with the declining budgets and concomitant declines in the number of new weapon systems, defense contractors face the same concerns as well as a focus on redesign and modification of existing systems. Future products from the defense industry must more carefully consider life cycle cost—not just acquisition cost.

To address these changing needs, industry has been adopting a method called concurrent engineering (CE) or Integrated Product Development (IPD). Concurrent engineering is the parallel development of the product definition, the manufacturing process definition, and the support process definition. It is accomplished by a multi-functional product development team composed of designers, manufacturing personnel, specialty engineers, the customer, and the user. Concurrent engineering focuses on customer

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[1] Army Materiel Command, *AMC Vision Paper for AMC Laboratories, Research, Development and Engineering Centers, and Test Community for Use in Developing Business Plans*, July 1991.

satisfaction (quality improvement) by making products more reliable, maintainable, and safe and by reducing cycle time and cost.

New enabling technologies are needed to help accomplish the goals of concurrent engineering. Among those are advanced communications for multi-enterprise product development and new analysis tools that interact with the computer-aided design (CAD) systems. Two additional technologies are Human Centered Technology (HCT), which provides analyses and documentation of the human-machine interaction as a system, and Group Support Technology (GST), which provides tools and techniques for groups to interact and make decisions cooperatively. Both these technologies place an emphasis on process, which is so important to successful concurrent engineering.[2]

The Acquisition Logistics Research and Development Activity[3] at Wright Patterson Air Force Base (WPAFB), Ohio, is actively investigating both HCT and GST. In order to ensure the development of these technologies with a focus on customer needs and the use of relevant technological developments, the laboratory has been involved in a strategic planning process for future R&D activities. This paper reports the results of research performed by an Institute for Defense Analyses (IDA) study team whose immediate goal was to help refine and sharpen the focus of the Acquisition Logistics R&D Activity's strategy for HCT and GST by providing information about, and analysis of, potential customers, relevant technological developments, and probable alternative strategies. On a broader scale IDA's goal is to help the Acquisition Logistics R&D Activity make better plans—to determine what the opportunities in the changing environment are and who specifically in this environment are potential customers.[4]

A. APPROACH

The research involved three parts: identifying customers for human centered technology and group support technology, assessing the present and future state of the enabling knowledge and technology for HCT and GST development, and devising R&D

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2 It has been said that concurrent engineering will not be successful without R&D devoted to process as well as product. The significant question is how R&D will be used to focus on processes.

3 This term refers to the Acquisition Logistics Branch, Logistics Research Division, Human Resources Directorate, Air Force Armstrong Laboratory, at Wright-Patterson Air Force Base, OH.

4 This approach follows the recommendations given in Michael E. Porter, *Competitive Advantage, Creating and Sustaining Superior Performance*, Collier Macmillan Publishers, 1985. Hereinafter referred to as *Competitive Advantage*.

strategies for the Acquisition Logistics R&D Activity to use for HCT and GST development. These strategies are outlined in Section B below and given in detail in Chapter VIII.

1. Identifying Customers for the Technology

The development of a strategic plan for R&D is influenced by many factors, not the least of which are the customer needs. This is an era, however, of swiftly changing customer needs in response to various international and national events and trends.[5] Specific customers were identified as the Air Force Materiel Command (AFMC), the Product Centers and System Program Offices (SPOs), the defense (specifically aerospace) industry, and the Air Logistics Centers (ALCs). For each of these potential customers, the specific processes, activities, and functions were described and those that could use HCT or GST were identified.[6] For each activity, a description of how HCT or GST could increase the activity's efficiency and output quality was developed. Future events and trends that could affect each type of organization and its specific activities were assessed (e.g., reductions in defense funding, reorganizations, and technology advances). The effect of implementing TQM, concurrent engineering, or IPD, and the use of current and expected Computer-Aided Acquisition and Logistics Support (CALS) technologies, were also considered. Detailed information for each of these four customers is contained in Chapters II through V

2. Assessing the Present and Future State of the Enabling Knowledge and Technology

The development of specific HCT and GST capabilities and products by the Acquisition Logistics R&D Activity will depend upon the present state of the art in, and future development of, the underlying scientific knowledge and enabling technologies. The IDA research team identified the relevant and necessary underlying knowledge and technology, assessed their present states, and forecasted their future development in Chapters VI and VII.

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5 In fact, the environment is changing so rapidly that numerous rewrites of this paper were required to reflect the changes. Any strategic planning effort should be a continual process to keep up with the rapidly changing world.

6 Porter, *Competitive Advantage*.

B. ALTERNATIVE R&D STRATEGIES

This section defines broad strategies that derive primarily from customer needs and identifies the strengths and weaknesses of each strategy with respect to the capabilities and location of the Acquisition Logistics R&D Activity. The general strategies are presented in order of decreasing importance with regard to Human Centered Technology (HCT) and Group Support Technology (GST) as judged by the various factors discussed. The introductory subsection gives overall strategies that we feel are important to the total Acquisition Logistics R&D Activity's goals.

1. Overall Strategies

The overall strategy is more of a marketing strategy than an R&D strategy because it applies to all the HCT and GST activities of the Acquisition Logistics R&D Activity. This strategy is to promote these technologies as *process* technologies. *Product* technologies are those technologies that improve the performance of the end product (i.e., weapon system); process technologies are those technologies that provide for the efficient and effective introduction of the product technologies into the product (traditionally these are manufacturing process technologies). During our concurrent engineering research at IDA, it has become evident that concurrent engineering will not survive without process technologies as well as product technologies.[7]

HCT is technology that is applied to the human interface with operational, support, and manufacturing processes to make them more efficient, safe, and affordable. GST is technology that is applied to the processes of design, planning, and improvement to make them more efficient, effective, and affordable.

The other overall strategy is for the Acquisition Logistics R&D Activity to become an active participant in the Concurrent Engineering Research Center (CERC) in Morgantown, West Virginia. Opportunities here involve putting the HCT models[8] that are developed on the concurrent engineering research testbed. Although this testbed is still in a

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7 Process technologies are an important part of the new Science and Technology Strategy of the Director, Defense Research and Engineering (DDR&E), and a primary element of Thrust 7 of that effort, Technology for Affordability. Dr. Robert White, president of the National Academy of Engineering, said in a seminar at IDA that process technologies were essential to the nation's competitiveness as well.

8 This opportunity exists not just for HCT or GST but for other concurrent engineering related tools, such as the Reliability and Maintainability in Computer-Aided Design (RAMCAD) system also developed by the lab.

research environment, it is integrated and can provide a good test for the model. In addition, the model will get high exposure. GST developed for concurrent engineering use can also be tested in this environment. Interaction with the CERC, as with Industry-University Research Centers, provides a low-cost activity for the exchange of technical information and products between the Acquisition Logistics R&D Activity and the Centers.

2. Human Centered Technology Opportunities and Strategies

Human Centered Technology as envisioned by the Acquisition Logistics R&D Activity (computational human factors, integration with CAD, tools for designing for high reliability and ease of maintenance) should play an important role in the new acquisition strategy as emphasis shifts from production to R&D with and without prototyping.

> Computer-aided design, computer simulation of operational environments, a design philosophy emphasizing high reliability and ease of maintenance, and automated flexible manufacturing would all make this type of research a more practical alternative.[9]

a. Manufacturing Domain

Today there is probably no greater issue affecting U.S. global competitiveness than the health of the industrial base and, consequently, the defense production base. Because of the current concerns for maintaining a defense industrial base, we see an opportunity for the Acquisition Logistics R&D Activity to provide HCT for the manufacturing domain as well as for their traditional customers in the reliability, maintainability, and supportability (RM&S) domains.

At the 1990 Autofact, a CAD/CIM exposition, new tools and capabilities that allow the consideration of manufacturing issues much earlier in design were demonstrated. Demonstrations showed technological advances in rapid prototyping, advanced visualization and animation as a prototyping alternative, data base integration, parametric design, and surface solids modeling. The following concern, however, was voiced by participants at the exposition:

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9 U.S. Congress, Office of Technology Assessment, *Redesigning Defense: Planning the Transition to the Future U.S. Defense Industrial Base*, OTA-ISC-500, U.S. Government Printing Office, Washington, DC, July 1991. (Hereinafter referred to as *Redesigning Defense*.)

Investment in the workforce, both to provide an increasingly safer and more productive work environment and to provide the necessary levels of training and education for world class performance, will further drain capability for other competitiveness investments.[10]

In the current environment of manufacturing industry, problems are not so much with the development of manufacturing technology as with the ability to adopt this technology in industry. Many of the problems associated with the successful adoption of the technology are people problems—e.g., the required skill levels, the inadequate human-machine interface.

A key finding of a 1990 Coopers & Lybrand survey, "Made in America III: The Globalization of Manufacturing," was that manufacturers perceive that difficulties in hiring, training, and retraining skilled workers are a major obstacle to globalization.[11] American manufacturers are aware that the future skill requirements of their employees will be significantly greater than in the past. "Manufacturers are spending tremendous amounts of money and resources on education and training, but there is still concern that the skill level of all employees may not be competitive with the Japanese workforce."[12]

Manufacturing Technology. The strategy here is to develop tools and techniques that would lead to an improved human-machine interface for manufacturing workstations, work cells, flexible manufacturing centers, and flexible repair centers. The customers of this strategy would be both industry (defense and commercial) and the logistics centers. Under the new acquisition strategy being proposed now in DoD, the organic manufacturing capability should increase. Reduction in overall procurement and the lengthening of programs may result in the Services' doing more in-house manufacturing in addition to repair.[13]

The growing interest in this area can be seen in the ESPRIT project in Europe, which focused on a similar effort called human centered technology for computer integrated manufacturing (CIM).[14] This project provided approaches to man-machine interfaces,

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10 "Industrial CALS: Capturing the Competitiveness Advantages," *SCAE Network*, September 1991.

11 "Coopers & Lybrand Survey: U.S. Manufacturers in the Global Market," *CAD/CIM Alert*, November 1990.

12 Remarks by Markus Clark, project manager, Manufacturing Strategy and Planning, Technical Affairs, Ford Motor Company, quoted in "NCMS Focuses on Industry/Academic Collaboration," *NCMS, FOCUS*, September 1991.

13 U.S. Congress, Office of Technology Assessment, *Redesigning Defense*.

14 Husband, T.M., "Human-Centered Technology for CIM Systems," Mechanical Engineering Department, Imperial College, London, United Kingdom.

software integration, and human centered job design. The impetus for this project was the recent interest in manufacturing system design based on retaining skilled craftsmen on the shop floor, not totally replacing them with factory automation. This practice of maintaining humans in the manufacturing loop also makes the introduction of flexible manufacturing systems (FMS) easier for mid- and small-sized companies.

The growth in simulation and modeling of manufacturing systems over the past decade has been facilitated by the availability of simulation languages for building and analyzing manufacturing models. The need to improve manufacturing operations and assess the effect of decisions before implementation drove this growth in simulation and modeling. Recent advances have also recognized that the manufacturing system must include the interrelationships among the physical manufacturing environment, the manufacturing management, and the worker. This idea reverses the traditional Tayloristic approach where manufacturing practice occurs in a vacuum, "without regard to human factors."[15]

The Acquisition Logistics R&D Activity has extensive expertise in developing man-models and human performance models and in getting them tested by industry. Although the lab has not been closely tied to the manufacturing community in the past, it has been successful in the concurrent engineering community. And often, technology developed for one specialty engineering function in a concurrent engineering team can easily be transferred for use by another. There is a close tie between maintainability and producibility just as there is between the processes of maintenance/repair/overhaul and production. If the lab can work closely with the MANTECH office, which it should because of its proximity, and take advantage of manufacturing expertise through consortia, the current lack of manufacturing experts within the lab should not be a barrier to implementation of this strategy. It is the human factors expertise, which the lab possesses, that the manufacturing community needs now.

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[15] Joseph A. Heim and W. Dale Compton, eds., *Manufacturing Systems—Foundations of World-Class Practice*, Committee on Foundations of Manufacturing, National Academy of Engineering, National Academy Press, Washington, DC, 1992.

Taylor, of course is Frederick Winslow Taylor, who fashioned the modern manufacturing organization with his concepts of optimization of individual job functions, separation of thinking from doing, and "disregard of the human side of the enterprise."

Products from this effort would include research reports, manufacturing technology design recommendations, and training recommendations. Models for design influence on manufacturing technology and for early training documentation at the soft prototyping stage would be developed on the order of Crew Chief; Design Evaluation for Personnel, Training, and Human Factors (DEPTH); and Operability Assessment System for Integrated Simultaneous Engineering (OASIS). Human models needed to interface with the manufacturing equipment would have more of an operator than a maintainer function and would require anthropomorphic, ergonomic, and cognitive simulation.

Human Issues in Manufacturing Technology Insertion. The strategy here is to develop a methodology or technologies to assess the potential human impact of new manufacturing technology on the shop floor and to devise human centered process planning for ultimate safety of the work force.

> The competitive position of U.S. manufacturing and service industries in world markets has been of growing concern to managers, scholars, and policy makers since the 1970s. As has always been true when greater efficiency and higher productivity are desired, managers have turned to new, sophisticated workplace technologies. New technologies, however, have not proved to be a panacea for all the problems of productivity. . . . [There is an] increasing awareness among mangers and researchers that solutions to fading competitive ability cannot be found in a mythical black box of technology. In fact, any important technology has profound human consequences, both positive and negative, which often remain unplanned or unanticipated. Consequently, it is often the organizational and human factors that either facilitate or constrain the ability of firms and coworkers to adopt and implement new technologies.[16]

While the previous strategy is concerned with optimizing the design of manufacturing technology with respect to the human operator/machine interface, this strategy is concerned with the implementation of the technology on the shop floor and the optimal design of the manufacturing organization and its processes with respect to the human factors of the work force.

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16 So begins the preface of *People and Technology in the Workplace*, National Academy of Engineering and the Commission on Behavioral and Social Sciences and Education, the National Research Council, National Academy Press, Washington, DC, 1991. The realizations contained in this quote prompted the National Academy to address these issues in a symposium on 13-14 March 1989. This reference contains the results of the symposium, including several case studies from industry.

The customers of this strategy are ultimately all of the industrial base. Customers in the mid- and small-sized businesses can be reached by joining the Technology Transfer Consortia and using the Cooperative Research and Development Agreements (CRDA). The following are technology transfer interfaces that the Wright Research and Development Center (WRDC) has used:

- Ohio Science and Technology Council[17]
- Ohio Advances Technology Center[18]
- Dayton Area Technology Network
- Ohio Technology Transfer Organization (OTTO)
- Federal Laboratory Consortium[19]

Additional customers include the logistics centers. The process planning, pre-production, and production planning functions are all customers of this R&D strategy.[20] Workflow and facility layout design and assembly or job design with an emphasis on safety and the handling of hazardous materials are ideal opportunities for HCT implementation.[21] Although ALCs are huge organizations, there does not seem to be enough of this kind of activity at present at the ALCs. Hence, this strategy may be viable for the Acquisition logistics R&D Activity only in the near term if industry is also a customer. This situation may be expected to change in the future as the ALCs pick up more of the manufacturing function in the modernization of weapon systems and strive to become more efficient. Again, an impediment to the implementation of this strategy could be the lack of manufacturing expertise in the lab.

Products include types of models such as Crew Chief, DEPTH, and OASIS that can be integrated with process models. Incorporation of hazardous materials (HAZMAT) handling and occupational safety considerations into a DEPTH-type model is very relevant for the ALC's process planning.

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17 A 17 May 1990 report to Governor Celeste made recommendations in the following 5 areas: technology trends, research infrastructure, technology transfer and commercialization, human resources, and science and technology policy.

18 AFHRL was a member.

19 Midwest Regional Coordinator is the Office of Research and Technology Application (ORTA), WPAFB.

20 Predominantly found in the Engineering and Planning Branches of the Product Directorates at the ALCs.

21 CAD is being used in the ALCs for these purposes more so than for design purposes.

b. Multi-Level Tools for System Design

The strategy here is to develop a multi-level HCT tool for use on various machines, at various stages in the design, at different levels of management. The rationale is that although detailed HCT tools are required for complete human/machine interface issues and the other human factor areas of concern, a less complex tool would be useful for conceptual design or for managers who need only a top-level view. Management needs a quick, high-level assessment without the detail required by designers. The customer base is widespread, including industry, the System Project Offices (SPOs), and the Air Logistics Centers (ALCs). Because of the resident expertise in the Acquisition Logistics R&D Activity from developing fairly complex models (e.g., Crew Chief) and getting them tested in industry, we believe that this strategy can build upon the Activity's strengths.

Although some may argue that the boundaries between the two technologies are blurred, we believe that HCT efforts should begin to be tied to solid modeling as well as computer-aided design. As discussed in Chapter IV, solid modeling allows analysis to be done much earlier than traditional CAD. Such a strategy would allow HCT to move into earlier phases of the design, and the earlier HCT analysis can be done in the design cycle, the greater emphasis it will have and the greater its ability to influence life cycle costs.

The product of this strategy would be a *suite* of computer tools. The upper-level tool would provide fast checks and highlight problems that the more detailed technology in a system such as DEPTH would integrate at a second level. A third level could be a human factors design checker to integrate with DEPTH and provide an automatic design checking capability.

c. Logistics Support Analysis Process

The strategy here is to provide HCT for the Logistics Support Analysis (LSA) process. This entails the development and use of a tool such as DEPTH for use in a design documentation mode for the Logistics Support Analysis Record (LSAR). Direct customers would be the defense industry and the SPOs, but an indirect customer is also the ALCs. They need to use the LSAR documentation but find it worthless to them in the way it is produced at present.[22] The whole LSA/LSAR process seems to be in need of help. If

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[22] Part of the problem, for which GST may be a solution, is that the right people aren't involved in the process—the ALCs are basically left out.

LSA could be done properly under the authority of the SPO, it would not need to be redone at the ALCs. All research and development for this strategy should be carefully aligned with the CALS information architecture.

d. Repair Validation and Verification Process

The repair validation and verification process is an iterative, time-consuming effort between industry (validation) and the ALCs (verification). Currently, it is done by real people on a real (physical) prototype. This alternative strategy would be to research and develop HCT for this process in a simulated or modeled environment, making use of the human models and the virtual (electronic) mock-up of the system. As a long-term strategy the Acquisition Logistics R&D Activity should consider a virtual reality system as an alternative to the human model. The user of the virtual reality system would be a real repair person.

In either way, sufficient detail would need to be incorporated into the model. For flight line maintenance evaluation, additional capabilities that could be incorporated in the human models include the following:

- The effects of adverse conditions
- Modeling of the senses
- The effects of fatigue and errors
- The effects of gravity
- Strength modeling.

3. Group Support Technology Opportunities and Strategies[23]

The people issues in GST, i.e., the decision-making or problem-solving aspects, not the distributed communications issues or the computer issues in document sharing, provide the best general opportunities for GST R&D by the Acquisition Logistics R&D Activity. This approach has the advantage of accenting the human factor, behavioral, and psychological expertise in the lab without having to rely on the computer or communications developments. There seem to be enough researchers emphasizing the computer aspects of GST, in some cases to the exclusion of the idea that the technology solution may not be the best solution for each group problem.

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[23] We were told by a reviewer that if the Joint Logistics Systems Center (JLSC) develops as currently planned, it will be the major customer for GST. Although not covered in the strategies listed here, it is a development that the Acquisition Logistics R&D activity should monitor closely.

a. GST for AFMC

The strategy here is to develop a research program for GST which would support the many team meetings involved with the AFMC. Several types of meetings are available to study: strategic planning meetings at ASD; Process Action Team (PAT), natural work group, and quality circle meetings in the TQM program throughout AFMC; and program reviews or requirements generation meetings in the SPOs. AFMC is a rich research environment because of the large number of meetings and the diversity of the groups holding them.

The first step in the strategy is to unobtrusively observe the teams and determine the dimensions of the types of meetings they hold. Different researchers in the field have identified different types of support required for different groups, but since no complete group taxonomy has been identified or agreed to in the research community, there is no consensus. Perhaps one of the first tasks of implementing this strategy would be to conduct a workshop—better yet, a group support system (GSS) session—with the GST research community in order to develop some consensus on these issues and have a better definition of user requirements.

Once the foundation for this strategy is laid and the types of technology that may be beneficial for each type of team is established, the teams can be introduced to various forms of computer support for which trust has been established during the first phase of the strategy, and GST tools specific to Air Force requirements may be developed. The introduction of the computer is probably best done at a GSS testbed facility in the lab where the participants' reaction to and satisfaction with the particular GST can be easily observed and recorded. A portable capability, on the other hand, may encourage greater use because of the relatively greater ease of introducing technology into a group's home environment. At this stage it will be important for the Acquisition Logistics R&D Activity to have trained facilitators for the group meetings if the meeting usually functions without one (all TQM group meetings should be functioning with a facilitator). If the group already has a facilitator, then only a technographer to operate the GSS and provide any necessary training will be required.

It is our experience that the first question we receive when proposing a group support system for a meeting is "Do you use it yourself?" The Acquisition Logistics R&D Activity will have a difficult time selling a GSS unless they themselves use it for their decision-making or problem-solving meetings. If they do and are happy with the results,

the word will spread and just scheduling the use of the GSS facility or portable system will become a full-time job.[24]

The products of this strategy would be technical reports in the beginning and software tools in the future.

b. Human Issues in Technology Insertion—Videoconferencing

The strategy here is to provide answers to the human issues in the adoption of and the efficient and effective use of videoconferencing technology. This strategy is very different from human issues in the manufacturing domain in that the manufacturing domain contains many simulations and models with which to interface an actual tool. This strategy involves taking a current technology, i.e., videoconferencing, and making it more compatible for human use.

Implementing this strategy would involve conducting research using the videoconferencing facility at WPAFB and observing, recording, and eventually conducting experiments with the various users of the facility. Products would be technical reports and formal methods or techniques that make this technology palatable.

In view of the reduced budget for travel and the current emphasis on involving all the key players for IPD and Integrated Weapon Systems Management (IWSM), videoconferencing will necessarily play a key part in product development. Videoconferences between the SPOs, the ALCs, and industry will occur more and more often until the high cost of distributed computer conferencing can be alleviated. Videoconferences are also held for TQM meetings between Commands. Customers of this strategy thus include multi-enterprise concurrent engineering or integrated product development teams, AFMC TQM teams, and IWSM teams. The primary customer may be the ALCs, however, because of their need for videoconferencing and overt resistance to using it. This support could help the ailing LSA/LSAR process as well.

c. Integrated Weapon System Management Process

This strategy involves researching the integrated weapon system management process and developing tools and techniques to aid the decision control in the group processes. The customer is the AFMC, specifically the SPOs and the ALCs; because of the

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24 We have seen this happen with the Fusion Center at Ft. Belvoir, VA.

way IWSM will be structured, the SPOs and the ALCs have similar responsibilities at different levels and times. This structure is convenient for the research activity because technology developed in this area for the SPOs, which can be locally studied, should also be applicable to the ALCs.

Since AFMC is a major organization and IWSM will greatly affect how the Air Force does business, finding a way to develop technology useful to the IWSM offers a significant opportunity to the Acquisition Logistics R&D Activity. Since AFMC headquarters and major program SPOs are located at WPAFB, some of the processes requiring GST should be easy to observe.

One of the specific and immediate customers of GST in the IWSM process may be the Center for Supportability and Technology Insertion,[25] Acquisition Modeling, (CSTI/AM) at WPAFB. The center's objective is to improve the acquisition process by providing SPOs, Program Executive Officers (PEOs), Service Acquisition Executives (SAEs), Product Centers, and Logistics Centers with information for planning, managing, and executing the program. Its immediate goal is to develop an acquisition model that captures the document preparation process. The Center's ultimate goal is to capture the IWSM process. Currently, the concept perceived by CSTI/AM is a single-user system, resident on individual personal computers (PCs). However, much of even the first phase of the model requires supporting the preparation of documents that require transfer and development among groups of people, not a single person. Thus the opportunity for groupware concepts to be incorporated into the Acquisition Model seems evident. The strategy here would be the cooperative research and development of a groupware capability for the acquisition model.

d. ALC Processes

The strategy here is to develop GST for the many group meetings and reviews required in the development and implementation of the repair/overhaul/manufacturing processes at the ALCs. The design of the production process at an ALC rivals in complexity the design of many products and requires many decisions among groups of people, in and out of meetings, at formal and informal reviews. Communication among the different branches and divisions at OC-ALC seemed to be a major problem; there is a need for better communication among the diverse groups. In our interviews, consultants and

[25] This is the former Acquisition Logistics Division of the AFLC.

other people knowledgeable about ALCs likened them to monstrous bureaucratic institutions, much like the defunct Soviet Union. Personnel on both sides of the management/maintenance continuum at OC-ALC expressed the desire for reduced time spent "putting out fires." This may suggest that decisions are not being made properly by involving the right people to guarantee implementation.

The products of this effort would be group support tools and techniques that rely more on formal methods and facilitation than on the use of computers by every member of the group. In fact, the latter idea probably should not be broached until some success has been demonstrated with the formal methods and facilitation. There appears to be a great need for help in the decision-making and planning processes at the ALCs. Initial work could focus on providing technical reports that recommend specific methods or techniques for groups like those found at the ALCs. To do this, the dimensions of the different types of groups at the ALCs would need to be determined.

e. Concurrent Engineering[26]

The strategy here is to develop GST for use by concurrent engineering teams in meetings. A large market exists for this type of technology because concurrent engineering teams require face-to-face meetings almost daily. Geographically distributed meetings are also held among team members in multi-enterprise developments and with customers and suppliers (but with less frequency). Many techniques and tools used for decision making or problem solving in face-to-face meetings could be used for distributed meetings if applied properly.

Unlike the personnel at the ALCs, engineers in industry are adept at using computers; they frequently use computers for their individual decision support. In contrast to GST for ALCs, computer support for group problem solving in a concurrent engineering team will require integration with analysis tools used by individual team members and will probably need to have a strong graphics capability.

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[26] Additional information on this topic can be found in two papers previously published by IDA and supported by the Acquisition Logistics R&D Activity: David A. Dierolf and Karen J. Richter, *Computer-Aided Group Problem Solving for Unified Life Cycle Engineering (ULCE)*, IDA Paper P-2149, February 1989; and David A. Dierolf and Karen J. Richter, *Concurrent Engineering Teams*, IDA Paper P-2516, Volume I: Main Text, and Volume II: Annotated Bibliography, November 1990.

In addition to industry, the SPOs are also customers for this strategy. The SPOs will have concurrent engineering teams of their own, although they will not function in quite the same way as those in industry. The types of decisions made in the SPOs will differ from those in industry. One problem area for this strategy is that many of the processes of concurrent engineering are product specific and most are company specific. Generic processes for decision support may be difficult to define because each company is rapidly developing its own techniques.

One of the strengths of this strategy for the Acquisition Logistics R&D Activity is all of its prior work in engineering design,[27] Unified Life Cycle Engineering, and concurrent engineering and its recognition in the field of concurrent engineering. Previous work such as RAMCAD, however, has concentrated on analysis tools for a specialty engineering function. User requirements are much easier to define for such a tool than for a process involving players from all the engineering functions.

Because a generic all-purpose GSS for concurrent engineering may be difficult to define, developers of specific strategies and products should—

- Publish technical reports on the dimensions of concurrent engineering group decision making and problem solving with recommendations for appropriate tools.
- Develop an expert-system type advisor to help a concurrent engineering team to choose correct GSS tools at appropriate times.
- Develop a design decision capture tool for use in concurrent engineering team meetings.
- Develop and publish interface requirements that allow lessons learned data bases to be used in a group setting.
- Develop and publish interface requirements for the formal methods in TQM [e.g., Quality Function Deployment (QFD)] to be used in a group setting by a concurrent engineering team.

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[27] Some of the systems design work of Gerald Nadler, co-chair of the symposium planning committee for *People and Technology in the Workplace*, was discussed in *A Survey of Research Methods to Study Design*, IDA Paper P-2155, which was supported by the Air Force Human Resources Laboratory.

C. SUMMARY

The strategies presented in this paper are results of a front-end analysis concentrating on customer requirements. It is important that the Acquisition Logistics R&D Activity involve the customers in determining the requirements for future research and development. Strategic planning should be an ongoing process instituted in the Acquisition Logistics R&D Activity to focus on customers requirements. They have made a commendable effort so far and continuing efforts in this area will ensure that their work receives the widest dissemination possible.

I. INTRODUCTION

Because of the changing environment in the Department of Defense (DoD), future weapon system research and development (R&D) and production will take place in a very different environment than that which has existed since World War II. The DoD budget has been declining since the mid-1980s, and with the end of the Cold War and the attendant change in threat, this trend is likely to continue in this decade. The Administration's acquisition approach for the 1990s is to scale back on production and protect R&D. The U.S. defense budget priorities for FY92/93 include people, technological advantage, efficient acquisition, and streamlined infrastructure. "DoD will continue to initiate and implement fundamental changes in the way it conducts its business . . . . The underlying philosophy is to centralize policies, procedures, standards and systems while decentralizing their execution and implementation."[1]

While these changing priorities will affect how the defense industry does business, so too will today's competitive global market affect how the commercial industry does business. In the commercial sector, competition from abroad has heightened concern for quality and increased the need for reducing risk, development cycle time, and, ultimately, cost. This new approach is reflected in the Total Quality Management (TQM) style of doing business. In the defense sector, with the declining budgets and concomitant declines in the number of new weapon systems, defense contractors face the same concerns as well as a focus on redesign and modification of existing systems. Future products from the defense industry must more carefully consider life cycle cost—not just acquisition cost.

To address these changing needs, industry has been adopting a method called concurrent engineering (CE) or Integrated Product Development (IPD). Concurrent engineering is the parallel development of the product definition, the manufacturing process definition, and the support process definition. It is accomplished by a multi-functional product development team composed of designers, manufacturing personnel, specialty engineers, the customer, and the user. Concurrent engineering focuses on customer

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[1] Army Materiel Command, *AMC Vision Paper for AMC Laboratories, Research, Development and Engineering Centers, and Test Community for Use in Developing Business Plans*, July 1991.

satisfaction (quality improvement) by making products more reliable, maintainable, and safe and reducing cycle time and cost.

New enabling technologies are needed to help accomplish the goals of concurrent engineering. Among those are advanced communications for multi-enterprise product development and new analysis tools that interact with the computer-aided design (CAD) systems. Two additional technologies are Human-Centered Technology (HCT), which provides analyses and documentation of the human-machine interaction as a system, and Group Support Technology (GST), which provides tools and techniques for groups to interact and make decisions cooperatively. Both these technologies place an emphasis on process, which is so important to successful concurrent engineering.[2]

The Acquisition Logistics Research and Development Activity[3] at Wright Patterson Air Force Base (WPAFB), Ohio, is actively investigating both HCT and GST. In order to ensure the development of these technologies with a focus on customer needs and the use of relevant technological developments, the laboratory has been involved in a strategic planning process for future R&D activities. The Acquisition Logistics R&D Activity brings several strengths to its strategic planning effort in the HCT and GST areas. This laboratory has long been recognized for its creative and productive R&D leadership in many aspects of the human system components of weapon system acquisition and logistic support technologies.[4] It is acknowledged worldwide for its expertise, and continues to have an interdisciplinary staff consisting of computer scientists, engineers, operations research analysts, and psychologists. It has strong links to leading academic researchers in its R&D mission area. It is experienced in working with design functions in aerospace firms and Air Logistics Centers (ALCs), and has been quite successful in demonstrating new logistic-support technologies in operational environments.

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2 It has been said that concurrent engineering will not be successful without R&D devoted to process as well as product. The significant question is how R&D will be used to focus on processes.

3 This term refers to the Acquisition Logistics Branch, Logistics Research Division, Human Resources Directorate, Air Force Armstrong Laboratory, at Wright-Patterson Air Force Base, OH.

4 To document the length and breath of experience in the area, one has only to scan the annual reports of the Air Force Human Resources Laboratory for the R&D programs and products of the Advanced Systems Division (AFHRL/AS) or the Logistics and Human Factors Division (AFHRL/LR), under which titles the current Logistics Research Division, Human Resources Directorate, Armstrong Laboratory (AL/HRG) was previously known.

Research staff at the Institute for Defense Analyses (IDA) have previously assisted the Acquisition Logistics R&D Activity in its strategic planning efforts. In one instance IDA researchers helped to develop a document that provides a comprehensive summary of the laboratory's resources and strengths and proposes a new mission statement for it.[5] In other efforts sponsored by the Acquisition Logistics R&D Activity, IDA researchers examined the issues of group problem solving for concurrent engineering. Results of this research can be found in IDA papers P-2149, P-2313, and P-2516,[6] which provide the foundation for the present study.

This paper reports the results of research performed by an IDA study team whose immediate goal was to help refine and sharpen the focus of the Acquisition Logistics R&D Activity's strategy for HCT and GST by providing information about, and analysis of, potential customers, relevant technological developments, and probable alternative strategies. On a broader scale IDA's goal is to help the Acquisition Logistics R&D Activity make better plans—to determine what the opportunities in the changing environment are and who specifically in this environment are potential customers.[7]

A. APPROACH

This study for the Acquisition Logistics R&D Activity began with a comprehensive literature search on human centered technologies as they relate to concurrent engineering or IPD, total quality management (TQM), and Computer-Aided Acquisition and Logistics Support (CALS)[8] efforts; it also continued the literature search previously conducted at IDA on group problem solving. The research involved three parts: identifying customers for human centered technology and group support technology, assessing the present and future state of the enabling knowledge and technology for HCT and GST development, and

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5 Air Force Human Resources Laboratory, Logistics and Human Factors Division (AFHRL/LRL), *Strategic Plan: Phase I*, draft, , 28 September 1989.

6 David A. Dierolf and Karen J. Richter, *Computer-Aided Group Problem Solving for Unified Life Cycle Engineering*, IDA Paper P-2149, Alexandria, VA, February 1989; William E. Cralley, David A. Dierolf, and Karen J. Richter, *Computer Support for Conducting Trade-offs in a Team Setting*, IDA Paper P-2313, Alexandria, VA, January 1990; David A. Dierolf and Karen J. Richter, *Concurrent Engineering Teams*, IDA Paper P-2516, Volume I: Main Text and Volume II: Annotated Bibliography, Alexandria, VA, November 1990.

7 This approach follows the recommendations given in Michael E. Porter, *Competitive Advantage, Creating and Sustaining Superior Performance*, Collier Macmillan Publishers, 1985. Hereinafter referred to as *Competitive Advantage*.

8 Definitions of each of these terms are given at the end of this chapter.

devising R&D strategies for the Acquisition Logistics R&D Activity to use for HCT and GST development.

1. Identifying Customers for the Technology

The development of a strategic plan for R&D is influenced by many factors, not the least of which are the customer needs. This is an era, however, of swiftly changing customer needs in response to various international and national events and trends.[9]

In its *Draft Strategic Plan* and the *Draft Plan for HCT*,[10] the Acquisition Logistics R&D Activity identified several classes of potential customers for new HCT and GST developments. For example, the Air Logistics Centers (ALCs), the other Air Force Laboratories, the System Project Offices (SPOs), and aerospace contractors were identified. The IDA research team began with this list and searched for other potential customers for HCT and GST implementation through the available literature and contacts with various consultants. During this search, it was determined that the formation of the Air Force Materiel Command (AFMC) through the combination of the Air Force Systems Command (AFSC) and the Air Force Logistics Command (AFLC) would have a fundamental affect on how the previously identified customers do business. Potential customers were contacted by telephone and at the CALS/CE Conference and the Third National Conference on Concurrent Engineering.[11] Site visits were made to the Oklahoma City Air Logistics Center (OC-ALC) and General Dynamics (GD), Convair Division, in San Diego. The Government Group Decision Technology Conference was also attended to determine the current technological state of GST and the extent of its use in the government.[12]

For each class of potential customer, the specific processes, activities, and functions were described and those that could use HCT or GST were identified.[13] For each activity, a description of how HCT or GST could increase the activity's efficiency and

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9 In fact, the environment is changing so rapidly that numerous rewrites of this paper were required to reflect the changes. Any strategic planning effort should be a continual process to keep up with the rapidly changing world.

10 Edward Boyle, Michael Young, and Capt. Ken Moen, *Human Centered Technology for Design*, AFHRL/LR Draft Plan, 1990. (Hereinafter referred to as *HCT for Design*.)

11 Held in Washington, DC, 11-14 June 1991.

12 Held at the Federal Executive Institute in Charlottesville, VA, 23-25 September 1991.

13 Porter, *Competitive Advantage*.

output quality was developed. Future events and trends that could affect each type of organization and its specific activities were assessed (e.g., reductions in defense funding, reorganizations, and technology advances). The effect of implementing TQM, concurrent engineering, or IPD, and the use of current and expected CALS technologies, were also considered.

2. Assessing the Present and Future State of the Enabling Knowledge and Technology

The development of specific HCT and GST capabilities and products by the Acquisition Logistics R&D Activity will depend upon the present state of the art in, and future development of, the underlying scientific knowledge and enabling technologies. The IDA research team identified the relevant and necessary underlying knowledge and technology, assessed their present states, and forecasted their future development.

3. Devising Alternative R&D Strategies

The research concluded with the development and evaluation of alternative strategies for the Acquisition Logistics R&D Activity's development of HCT and GST. Each strategy includes a description of one or more HCT or GST R&D products, identifies specific potential customers, and describes the potential users' expectations of the proposed product(s). Each strategy delineates the specific activities that the Acquisition Logistics R&D Activity could undertake to develop and deliver the product(s). Among the factors considered in appraising the alternative strategies are the attractiveness of potential customers and the capability of required enabling knowledge and technologies to support the strategies. In developing these strategies the researchers considered the strengths of the Acquisition Logistics R&D Activity and its special access to customers, data, and technologies.

4. Conducting Discussion Meetings

During the course of this research, an interim and a final discussion meeting were held at the Acquisition Logistics R&D Activity at WPAFB, OH. The meetings included progress briefings on the findings of the research by the IDA team and allowed the IDA research team and the Acquisition Logistics R&D Activity staff to share ideas on how best

to use the study findings to develop and refine a strategic plan for HCT and GST R&D. The interim discussion meeting was conducted at the conclusion of the customer evaluations, and the final discussion meeting presented the preliminary strategies. Because strategic planning should be an ongoing, interactive process among the decision makers of the Acquisition Logistics R&D Activity, an anonymous session using a group support system (GSS) was also conducted for the members of the Activity. Comments generated during this session were considered in the final evaluation of the strategies.

B. OUTLINE OF THE REPORT

The rest of this chapter gives relevant background information and definitions of the various topics that will be discussed in this paper. The first few chapters thereafter describe the processes by which potential customers for the Acquisition Logistics R&D Activity accomplish their missions. Chapter II covers the formation of the Air Force Material Command (AFMC) and the changing environment that will result. Chapter III gives details on the activities and functions of the Product Centers, specifically the System Program Offices (SPOs) in the Aeronautical Systems Center at WPAFB. Chapter IV discusses the defense industry in general as a customer with specific information on GD Convair Division. Chapter V includes information on the Logistics Centers and specifically the OC-ALC. The enabling knowledge and technology for HCT and GST is discussed in Chapters VI and VII, respectively. Chapter VIII presents and assesses the alternative strategies for the Acquisition Logistics R&D Activity.

C. RELEVANT BACKGROUND AND DEFINITIONS

This section further defines the concepts of Total Quality Management (TQM), concurrent engineering, or Integrated Product Development (IPD), and Computer-Aided Acquisition and Logistics Support (CALS) as a basis for the ensuing discussion of potential customers and relevant technological development.

1. Total Quality Management

TQM is a management philosophy whereby everyone in an organization collaborates to achieve customer satisfaction through continuous process improvement, error prevention, and the elimination of waste. TQM stresses building quality into all of the processes of an organization, whether the organization performs one or a combination of the functions of defining, building, or servicing products for its customers. TQM stresses

teamwork—the process improvement is achieved through teams of people meeting to solve problems and improve the process(es) for which they are responsible. Such teams may be called Process Action Teams (PATs), Quality Circles, Natural Work Groups, or Problem-Solving Teams.

Commonly described characteristics of organizations subscribing to the TQM philosophy include:

- A process orientation and a commitment to continual improvement.
- A focus on customer satisfaction.
- A scientific approach to problem solving.
- An emphasis on human resources and teamwork, including continued education and training.
- Strong management commitment and leadership.

2. Concurrent Engineering and Integrated Product Development

All of the characteristics of TQM are also desirable attributes for an organization practicing concurrent engineering or Integrated Product Development (IPD).[14] Concurrent engineering is a systematic approach to the integrated, parallel design of products and their related manufacturing, operating, and support processes to increase customer satisfaction. In a concurrent engineering approach, all phases of a product's life-cycle are considered through the integration of the manufacturing process planning and product-support planning into the product design process. In its fundamental sense, concurrent engineering is TQM applied to product development, and the goals of concurrent engineering are accomplished through multi-functional teams of designers, specialty engineers, suppliers, customers, marketing personnel, etc. Because concurrent engineering is applied to engineering functions, however, an emphasis on computer support is also required. The concurrent engineering approach typically involves three related elements:[15]

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[14] Some people distinguish between concurrent engineering and IPD. For example, GD Convair uses the term concurrent engineering for processes between Departments or Divisions, and IPD for processes between Directorates. We do not make a distinction and use the term concurrent engineering in the broadest sense to involve multi-enterprise teams of people including suppliers and customers.

[15] Robert I. Winner, Jim P. Pennell, Harold E. Bertrand, and Marco M. G. Slusarczuk, *The Role of Concurrent Engineering in Weapons Systems Acquisition*, IDA Report R-338, Alexandria, VA, December 1988.

- Engineering process initiatives to change the institutional and organizational engineering culture with the highest top management support so that multi-departmental, multi-disciplinary, multi-functional teams can be formed to address common engineering design issues and processes concurrently.
- Integration of solid Modeling, Process Modeling, Computer-Aided Design (CAD), Computer-Aided Engineering (CAE), and Computer-Aided Manufacturing (CAM) tools during product development. For this purpose, concurrent engineering utilizes computer-based tools that encourage and facilitate team members' sharing of product and process models and data bases relevant to the product development.
- A systematic, scientific structure for team solutions of product and process design problems, supported through concurrent engineering team interactive uses of formal analytic methods.

a. The New Product Development Environment

During the 1980s several DoD-sponsored programs worked toward integrating life cycle factors into the early design phases by focusing on single features, known as the "ilities," e.g., reliability, maintainability, supportability, producibility. This approach ultimately led to the institutionalization of separate terminology and analysis methods and to the formation of stovepipe functional organizations in industry and government.[16] As stated in The Pymatuning Group Report, "This 'single feature' or 'ility' approach has unfortunately been conducive to separate, non-interacting program offices and separate budget line items in the DoD acquisition process each directed to a 'single feature improvement' objective. In addition, it has led to a cumbersome, sequential, and prohibitively costly, sub-optimized procurement process."[17] Concurrent engineering offers the opportunity to escape this single feature mentality and approach product development in a systematic, integrated, and collaborative way. The idea that designers have to be provided with tools that provide the specialty engineering checking function has progressed to a new view of product development. In this view, product development is accomplished with a team of designers and specialty engineers collocated physically, if possible, or by an electronic network.

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[16] Aeronautical Systems Division (ASD), *Guidelines for Creating and Managing an Integrated Product Development Process*, White Paper, Wright Research and Development Center (WRDC), Wright-Patterson AFB, OH, 1990.

[17] Pymatuning Group, Inc., *Industrial Insights on the DoD Concurrent Engineering Program*, Arlington, VA, October 1988.

This change in thinking under concurrent engineering is aided by the formal, scientific approach to problem solving introduced to concurrent engineering through Total Quality Management. Such an approach is essential to thoroughly understand the interrelationships among the defining, building, and supporting phases of a product's life cycle. Such techniques as experimental design, simulation modeling, and mathematical analyses seek to provide a deeper understanding of these relationships and determine root cause effects. The change in thinking accompanied by the formal methods and tools will change the way the specialty engineers ("ility" specialists) function. For example, reliability engineers in the traditional, sequential design process performed analyses on a proposed product design to determine whether the design met the reliability specifications. The result of the analyses was typically, then, a yes or no answer. Under concurrent engineering, the reliability engineers must learn to take a different approach to their task and solve a different type of problem. They need to determine the root causes of predicted failures and suggest changes in the design that will lead to a more reliable product. In effect, the specialty engineers need to learn to function more as a designer, finding problems and identifying solutions. Technologies that not only aid prediction and analysis but also help find root causes and solutions to problems in the specialty engineering areas are needed.[18]

b. Modifications and Redesign

In the wake of changing world geopolitics, the U.S. military force structure is slated to diminish, and so too will Air Force budgets. With the weapon system acquisition dollars likely to decrease even more quickly than the overall budget, fewer and fewer new weapon systems will be developed. The urgent production and deployment of new systems required during the Cold War is no longer necessary. The shift will be toward the overhaul, remanufacturing, retrofitting, and upgrading of deployed systems.[19] The emphasis will be on modifying, redesigning, and upgrading present weapon systems, processes collectively known as "modernization" in the current environment.

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[18] Although this analysis of the situation has been derived from prior research at IDA, these ideas were also expressed by personnel at GD Convair during our site visit.

[19] U.S. Congress, Office of Technology Assessment, *Redesigning Defense: Planning the Transition to the Future U.S. Defense Industrial Base*, OTA-ISC-500, U.S. Government Printing Office, Washington, DC, July 1991. (Hereinafter referred to as *Redesigning Defense*.)

In an austere budget environment, modernization will predominate, as opposed to new system development. Therefore, quality has a vital role in modernization and also in the repair and overhaul of equipment.[20]

Changes and upgrades have always been made to systems based on changing user requirements, the incorporation of more systems functions, the identification of reliability or safety problems, or the availability of newer technologies.[21] The DoD is now ready to emphasize the insertion of proven technologies into existing weapon systems over the production of new weapon systems, provided the technology insertion can meet the operational needs.[22] The expected longer service life of the deployed systems will increase the importance of maintenance and overhaul capability in the long run. (In the short run, maintenance requirements may diminish due to the retirement of systems to balance the reduced force structure.)[23]

In that environment, lessons learned knowledge bases will be extremely valuable to concurrent engineering teams. There is a problem, however, with such data bases as they now exist. The data are not in a form that the concurrent engineering team members can use—they need the analysis and knowledge of why something failed, not just the information that it did fail. Legacy data will need to be digitized on existing systems, and legacy systems will need to be updated as well.[24]

3. Computer-Aided Acquisition and Logistics Support and Contractor Integrated Technical Information System

The goal of the DoD-Industry Computer-Aided Acquisition and Logistics Support (CALS) initiative is to evolve from the present paper-intensive processes to digital-flow processes that will capture product design and support information in computer-readable digital formats for use and reuse without regeneration. CALS emphasizes information in digital form—repair manuals, technical orders (TOs), and related product support

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20 Minutes of the DoD Quality Leadership Forum II, 15 November 1991.

21 James V. Jones, *Engineering Design: Reliability, Maintainability and Testability*, TAB Professional and Reference Books, Blue Ridge Summit, PA, 1988.

22 Department of Defense Fact Sheet, *A New Approach to defense Acquisition.*

23 U.S. Congress, Office of Technology Assessment, *Redesigning Defense.*

24 Dr. Jacques Gansler (TASC), "CALS and Concurrent Engineering: Essential Ingredients in the Needed Cultural Change," *Proceedings of the CALS&CE Washington '91 Conference & Exposition*, Featuring the Third National Symposium on Concurrent Engineering, 10-14 June 1991, pp. 341-350.

information—as well as the creation of automated reliability and maintainability tools that can integrate with CAD tools.

CALS began (and continues) as an effort to create, maintain, transfer, and use product-support information in digital form. Since it originally focused primarily on the documentation necessary for logistic-support functions, an early CALS product was the development of a digital format for the Logistics Support Analysis Record (LSAR), which provides the standard basic data in the Integrated Logistics Support (ILS) process. The CALS initiative has broadened its focus to include universal data-exchange standards. Such data standards will help the DoD to receive, store, distribute, and use system technical data more efficiently and effectively through digital-flow processes, in place of the currently used paper-intensive methods. Examples of CALS standards are shown in Table I-1. Standards development is coordinated by the National Institute of Standards and Technology (NIST) in Gaithersburg, MD.

Table I-1. CALS Standards and Applications

Standard	Application
SQL	Structured Query Language
Government Open System Interconnection Profile (GOSIP)	Communications Protocols
Open System Interconnection (OSI)	Communications standard
POSIX	Operating System Interface
International Graphics Exchange Standard (IGES)	CAD, Vector Graphics • Tech Manual Illustrations • Engineering Drawings • Electronics • Numerical Control
Standard Generalized Markup Language (SGML)	Automated Publishing • Tech Manuals
GRP 4 Raster	Raster Scanned Images • Engineering Drawings • Tech Manual Illustrations
CGM	Vector Graphics • Tech Manual Illustrations

The *CALS Program Implementation Guide*[25] cites as goals, the ". . . attainment of increased levels of interfaced, or integrated functional capabilities, *and* specification of requirements for limited government access to contractor data bases, *or* delivery of technical data to the government in digital form." Attainment of these goals will provide DoD the means to improve all aspects of acquisition and logistic support—for example, in areas such as life-cycle maintenance, spares reprocurement, and maintenance facilities and training.

Today, CALS objectives include the creation of digital data bases, linkages, and integration to provide for the digital-flow of all engineering information. Since the goal of the concurrent engineering process is the integration of all engineering efforts, the concurrent engineering and CALS goals complement each other. "CALS initiatives to improve technical data creation, management, and use provide an enabling environment that will accelerate the application of concurrent engineering concepts and their consequent benefits."[26]

Under the CALS initiative, each firm participating in a production project would need to provide data to its suppliers and customers. The services thus provided are called a Contractor Integrated Technical Information System (CITIS). CITIS will provide a contractor-managed service using integrated data bases. It will serve the acquisition manager, the weapon system contractor, and the logistics life cycle managers by providing both authorized access to and management of information. The physical location of the data may be distributed among contractor and government automated data processing (ADP) systems.[27]

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25 Department of Defense Computer-Aided Acquisition and Logistics Support (CALS) Policy Office, *Department of Defense Computer-Aided Acquisition and Logistics Support (CALS) Implementation Guide*, Military Handbook MIL-HDBK-59, Washington, DC, 20 December 1989.

26 ibid.

27 ibid.

The CITIS is "the collection of automated data processing systems and applications used by the contractors (i.e. the prime(s) and all subcontractors) to enter, update, manage, retrieve, and distribute technical data from a specific Integrated Weapon System Data Base."[28] The missions of the CITIS are as follows:[29]

- To provide a unified view of the design, development, support, management, and acquisition process for complex products. Build in support and feedback.
- To ensure that the system enables and enforces design for manufacturability, test, support, readiness, and life cycle cost.
- To create and store data elements in one location and to access them from as many locations as possible.
- To enable Total Quality Management (TQM).
- To provide a Command, Control, Communications, and Intelligence (C^3I) program for engineering/manufacturing and a Just-In-Time information supply facility. Negotiate visibility of customer over information.
- To support and be compatible with ongoing customer development of CALS/CE capabilities.

In addition to CALS technologies, Human Centered Technology (HCT) and Group Support Technology (GST) are also enabling technologies for concurrent engineering. These technologies may be new to the reader, and are defined therefore in the following sections.

4. Human Centered Technology

Human Centered Technology (HCT) involves the use of computers to help define and document the role of people in system design, operations, and support. The development and implementation of HCT will foster more extensive and earlier evaluation of human-machine-workplace integration issues than is currently possible in product development and will provide for the efficient use of and planning for human resources in product and process design.[30]

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28 ibid.

29 Len Bullard (GE Automated Systems Department), "Enterprise Engineering for Concurrent Integrated Product Development and Support Environments," *Proceedings of the CALS&CE Washington '91 Conference & Exposition*, Featuring the Third National Symposium on Concurrent Engineering, 10-14 June 1991, pp. 195-247.

30 Boyle, Young, and Moen, *HCT for Design*.

One approach to HCT is a computational human-factors approach to incorporate human factors considerations into product design and documentation—to focus on the product of design as a human/machine system through task simulation, visualization, and analysis. To this end, HCT development fosters the use of computer graphics visualization technologies to represent the relevant aspects of human maintainability and operability performance and to provide design influence.

The use of computers to simulate or replicate, often, but not necessarily, with graphics, the behavior of a person in a work environment is called *Human Performance Modeling*. These simulations are often instrumented with a theory, taxonomy, principle, or data base on human behavior (e.g., the Human Operator Simulator (HOS), Fitts' Law). The field has a strong emphasis on modeling of cognitive processes of operators in information rich environments. The Army-NASA Aircraft/Aircrew Integration program (A3I) calls itself a human performance modeling system. Cognitive processes modeled here include vision.

Human-Modeling[31] involves the use of computer graphics to create the illusion of a person or persons on a display. These are basically visual aids for assessing person/machine "physical fitness." That is, the human models deal with anthropometry, biomechanics, biodynamics, and, to a lesser extent, person/machine interface problems. Many connect with CAD directly or indirectly as design evaluation tools. Examples are Crew Chief, SAMMIE, JACK, CAR, and COMBIMAN.

Joining human models with human performance "process" models to create viewable simulations is the new frontier. The A3I program and CAT are good examples of this trend. New work by the Army Research Institute is attempting to join a new version of the Human Operator Simulator, a well-known process simulation, with an anthropometric human model using Microsaint task networking. In contrast, Crew Chief and the other human-models have had anthropometric and biomechanical objectives only. In general, they do not implement or display or simulate a theory about human performance capabilities but instead display known human physical characteristics usefully. Even so, there is a tendency to group the man-models under the rubric of human performance modeling.

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31 Also called man-modeling. The less sexist term, human figure modeling, is also used.

Human models are being used in industry currently. McDonnell Douglas stresses the following reasons why it uses human models:[32]

- More than 50 percent of total production time is assembly or fastening, yet mechanical fasteners represent less than 50 percent of assembled product cost.
- While aerospace equipment is becoming more reliable, the number and type of accidents attributable to human errors have not changed much.
- About 35 percent of aircraft operational costs are related to maintenance, and human engineering factors have a major impact on a vehicle's maintainability.

HCT can be used to develop other CALS-compliant computer-based tools for the concurrent engineering team. These tools can include—

- Computer-Aided Design/ Computer-Aided Engineering (CAD/CAE) tools that address human factors engineering and manpower, personnel, and training (HFE/MPT) tradeoffs in design and human interface modeling.
- Product development aids that enable the analysis of human-machine interaction.
- Design aids that can help define and document the processes associated with the product design (manufacturing, operational, support).
- Tools that draw upon data bases that include data describing human capabilities, e.g., physical human factors and cognitive human factors.

The goal of HCT development in the maintainability arena is not only to provide task simulation tools for creating design influence of human factors and manpower, personnel, and training (MPT)[33] in the concurrent engineering process but also to create design documentation of the human-machine interaction in the support process. This documentation role is linked to the Integrated Logistics Support (ILS) processes and the Logistics Support Analysis (LSA). The Logistics Support Analysis Record (LSAR)[34] is

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32 William B. Scott, "Computer Simulations Place Models of Humans in Realistic Scenarios," *Aviation and Space Technology*, 24 June 1991, p. 64.

33 In the classical view, MPT has to do with specifying how many people (M) with what skills (P) and what preparation (T) it takes to staff a given function effectively and economically. M is spaces, P is faces, and T is how to replace the faces in the spaces. In the broader sense, MPT means "human resources." MPT deals with the system level of analysis and is a first cousin of "human factors." The latter has largely to do with adaptive person/machine integration. HF does not aggregate requirements beyond the single person or individual team. MPT does. That is to say, if you deal with a squadron, there is MPT. If you deal with a single airplane or C^2 node, you have human factors. In this sense, HF is micro, MPT is macro. HF is related more to the system's performance. MPT is related more to the system's budget. MPT is part of Integrated Logistics Support.

34 Described in MIL-STD 1388-1/2A/2B.

the major repository for the maintenance and operation technical data for new and upgraded military systems. The maintenance information that eventually goes into the technical manuals comes from the LSAR records, primarily the C and D records. The LSAR includes safety, failure modes and effects analysis (FMEA), and support equipment (SE) requirements to support the human engineering, technical training data development, and certain aspects of MPT analysis and planning. HCT can provide means to describe the maintenance work required by these standards. In this role, HCT is clearly aligned with CALS functions (Figure I-1).

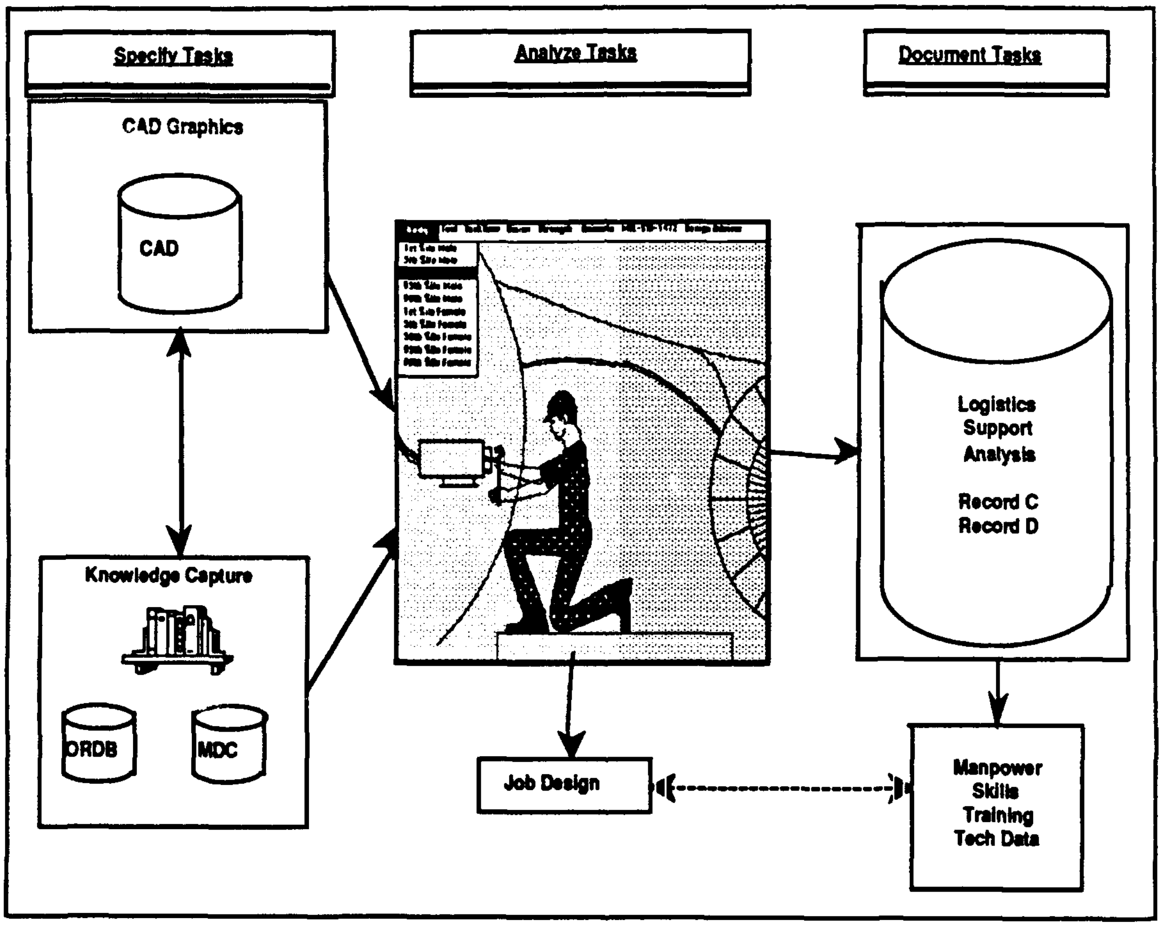

Figure I-1. Uses for a Human Model

5. Group Support Technology

Group Support Technology (GST) is the term used for computer-based support and formal methods used by a group or team of people to improve communication, collaboration, and cooperation—in essence, those technologies that help groups of people work cooperatively more easily and more effectively.[35] Computer tools developed using GST are often called Groupware or Group Support Systems (GSS).

Group support technologies are included in Groupware, electronic meeting systems (EMS), and group decision support systems (GDSS). Groupware is a term that has been used to describe work-group computing systems that vary from basic systems such as multi-user data bases, local area networks, and electronic mail (E-mail) to systems that support text sharing and task management. An EMS—

> supports group meetings, which may be distributed geographically and temporally. The EMS environment includes, but is not limited to, distributed facilities, computer hardware and software, audio and video technology, procedures, methodologies, facilitation, and applicable group data. Group tasks include, but are not limited to, communication, planning, idea generation, problem solving, issue discussion, negotiation, conflict resolution, systems analysis and design, and collaborative group activities such as document preparation and sharing.[36]

The term GDSS connotes a system that supports group decision making using computer support with formal methods in a facilitated meeting setting.[37] A GDSS is a "sociotechnical package" that comprises hardware, software, organizationware, and people. GDSS are "aimed at removing common barriers to group work and communication, such as unequal consideration of ideas, dominance by individuals, peer pressure, and loss of autonomy" and are used to "identify problems and opportunities, refine understanding of the consequences of options, and clarify the role of the

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[35] Capt. Raymond R. Hill, "Enhancing Concurrent Engineering Using Quality Function Deployment Based Tools," Air Force Human Resources Laboratory, Logistics and Human Factors Division, WPAFB, OH. (Hereinafter referred to as "Enhancing Concurrent Engineering.")

[36] Alan R. Dennis et al., "Information Technology to Support Electronic Meetings," *MIS Quarterly*, December 1988, pp. 591-624. (Hereinafter referred to as "Information Technology.")

[37] The facilitator of a meeting is a person with process knowledge about the running of the meeting and the use of the GDSS system. He or she does not necessarily have content knowledge about the meeting subject. It is envisioned by some that in the future, GDSSs will facilitate themselves.

decisionmakers in the process of dealing with these issues."[38] A GDSS can include such systems as—

- *Electronic boardrooms*, consisting of a computer and audiovisuals
- *Teleconferencing facilities*, consisting of a computer and communications
- *Local area group nets*, consisting of a computer and interactive conferencing
- *Information centers*, consisting of a computer, data bases, and retrieval tools
- *Decision conferences*, consisting of a computer and decision models
- *Collaboration laboratories*, consisting of a computer and collaboration tools.

In addition, the following types of tools can be included in a GDSS:[39]

- A *session director* that aids a meeting facilitator in the selection of tools.
- An *electronic brainstormer* to aid manual brainstorming.
- An *issue analyzer* that helps group members "identify and consolidate key focus items resulting from idea generation."
- A *voting aid* that collects private ballots and aids in ranking of choices by a number of methods.
- A *topic commenter* that supports solicitation of ideas and additional details.
- An *aid to policy formation* that supports the generation of policy statements through iteration and group consensus.
- An *organizational infrastructural aid* that helps to "capture the characteristics of organizational data sets, information systems and structure."
- *Stakeholder identification and assumption surfacing* to help evaluate the implications of a proposal. Stakeholder assumptions are identified and analyzed graphically.
- An *alternative evaluator* to support multi-criteria decision making.

Decision making involves problem identification and definition, generation of alternative solutions, and the choice of alternatives; it usually ends with the *choice* phase. Problem solving goes beyond the choice phase to include implementing the solution and

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38 Kenneth L. Kraemer and John L. King, *Computer-Based Systems for Cooperative Work and Group Decisionmaking: Status of Use and Problems in Development*, Public Policy Research Organization, University of California, Irvine, September 1986.

39 These are tools included in the PLEXYS system at the University of Arizona (Dennis, et al., "Information Technology").

monitoring its effectiveness—phases that may benefit from Groupware. Figure I-2 represents a model of Groupware options proposed by the Institute for the Future. It illustrates that temporal and spatial distances between group participants are important dimensions of developing and choosing appropriate GDSS. This paper will refer to any system that supports group *problem solving* as a group support system (GSS) unless its specific nature is relevant to the current discussion.

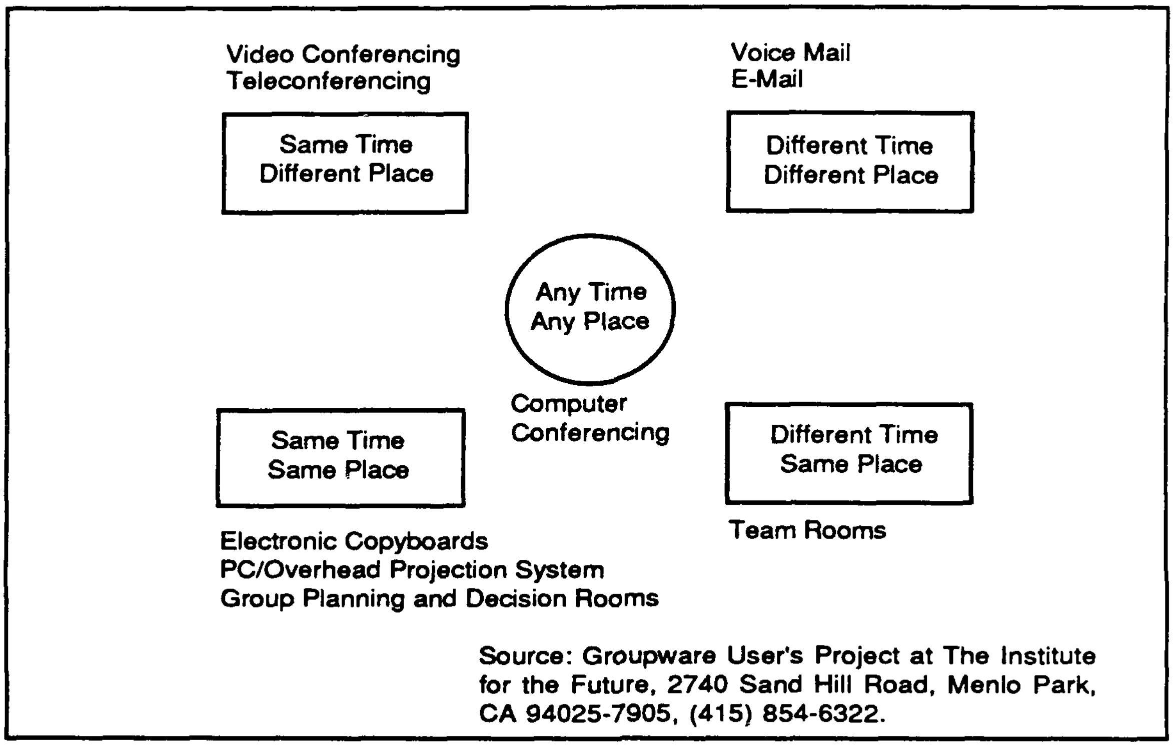

Figure I-2. 4-Square Map of Groupware Options

Group Support Technology appears to have many applications for the Department of Defense and the individual Services. It can enhance decision making related to the development of weapon system requirements and source selection. It can help capture the rationale behind system requirements, providing a means to develop cause and effect relationships between requirements and cost, and it can help document those relationships. GST can help trace the derivation of requirements or trace a test plan to the original requirements that drove it.[40] GST can also be helpful to contractors performing engineering design, facilitating contact and cooperation within and among concurrent engineering teams, across enterprises, and between the government and the contractor.

[40] Hill, "Enhancing Concurrent Engineering."

In the conceptual stages of product development, many problems are not amenable to traditional CAD solutions. Group problem-solving tools can support the team decision-making process and provide documentation of the design decision rationale. They should stimulate and support cohesive concurrent engineering team interactions and decisions, focusing on the process of product development as a system of collaborating people and can include both—

- Group Support System components and Groupware designed to facilitate design decisions made collectively by members of the concurrent engineering team.
- Formal group problem-solving methods, i.e., tools that enhance the scientific approach to problem solving—getting at the root causes.

The computer-based tools developed using HCT and GST will fill roles in both design and design documentation. Thus, these technologies are compatible with, and will further support the development of, both concurrent engineering and the DoD-Industry Computer-Aided Acquisition and Logistics Support (CALS) initiative. Both HCT and GST can be used to develop tools to be embedded as part of the CALS initiative into Computer-Aided Design (CAD), Computer-Aided Engineering (CAE), and Computer-Aided Manufacturing (CAM) processes, to become an enabling technology for the concurrent engineering process. However, the broader implications for GST must not be overlooked in the current environment:

> Organizations are undergoing radical changes in both their use of technology and their basic practices. We can expect that these changes will accelerate as the pressures continue to grow. Managers are faced with radical restructuring initiatives to support the downsizing, downscaling and delayering of objectives. The growth of interfunctional teams and often cross-organizational teams is leading to further initiatives in the establishment of "groups" and cooperative clusters of both short and long term duration. Integration within and across the organizational boundaries is further stimulating interest in leveraging [group support] technologies to enable and support work of groups and teams. Whether these are teams with a specific mission, standing committees that have a regular or recurring work schedule, or specially assembled groups that will have little cooperation beyond the current task at hand, each has different interests applying information technologies to support these meetings and other group work.[41]

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[41] Izak Benbasat and Benn Konsynski, "Introduction to Special Section on GDSS," *MIS Quarterly*, December 1988, pp. 588-590.

II. AIR FORCE MATERIEL COMMAND

On 1 July 1992, the Air Force Systems Command (AFSC) and the Air Force Logistics Command (AFLC) will combine to become the Air Force Materiel Command (AFMC), which will be located at Wright-Patterson Air Force Base (WPAFB), OH. The formation of this command will affect not only the way that the Acquisition Logistics R&D Activity does business, but also the way that the laboratory's potential customers do business. In addition, the IDA study team recognizes that the emphasis on the integration of so many activities for AFMC presents potential applications for Group Support Technology (GST) and Human Centered Technology (HCT) within the Command itself. This chapter discusses the proposed organization of the Air Force Materiel Command and the reorganization that has occurred in the AFLC to enable the combination of commands.

A. AIR FORCE MATERIEL COMMAND PLAN

The AFMC will direct a work force of close to 130,000 military and civilian employees, including most of the Air Force scientists and engineers. With over 10,000 engineers responsible for weapon system integrity and product improvement, an integrated process will be essential. AFMC's budget will be nearly half of the total Air Force budget. In its mission statement, the AFMC maintains:

> In partnership with our users, we develop and use technology to produce superior weapons systems and logistics support to enhance combat superiority, readiness, and sustainability.

The goals and objectives of the integration of the two commands are as follows:[1]

- **Goal:** Satisfy our customer's needs. . . in war and peace.

  Objective 1: Understand, through sustained interaction, our customers and their requirements, and provide options, including those available through other services, which are the basis for customer decisions and satisfaction.

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1 James A. Morrow, AFLC Public Affairs, "Command Leaders Set AFMC Objectives," *Skywriter*, 14 February 1992.

Objective 2: Ensure a robust AFMC war-fighting posture, including transition from peace to war.

Objective 3: Be our customers' supplier of choice by meeting cost, schedule and performance base lines; enhancing customer support; and lowering life-cycle costs.

Objective 4: Meet anticipated customer needs by planning for and securing continuing support of capital investments in the AFMC infrastructure.

- **Goal:** Enable our people to excel.

Objective 1: Create, implement and communicate a career development program for all military and civilian personnel in the command.

Objective 2: Invest in our people by providing the necessary education and training.

Objective 3: Move decisions to the lowest level, expand individual responsibility and authority, and seek and provide feedback.

Objective 4: Champion and implement personnel management changes that enhance productivity and job satisfaction.

Objective 5: Optimize the work force mix to conduct the AFMC mission.

- **Goal:** Sustain Technological Superiority.

Objective 1: Continuously improve the quality and relevance of Air Force laboratory science and technology programs.

Objective 2: Transition technology rapidly to applications, to include organic infrastructure.

Objective 3: Leverage the science and technology of other defense and government labs, allies, academia, and industry.

- **Goal:** Enhance the excellence of our business practices.

Objective 1: Enhance the competitiveness of our operations by improving throughput and decreasing inventory and operating expense in everything we do.

Objective 2: Expand and mature Integrated Weapon System Management (IWSM) by continuously improving teamwork, policies and processes.[2]

Objective 3: Champion environmental responsibility in design, test, and support, and industrial processes.

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2 IWSM is described in the following subsection.

Objective 4: Increase our business with high-quality suppliers to control and improve delivered products and services at the best value.

Objective 5: Pursue joint solutions, interservicing and interoperability in our business practices.

- **Goal:** Operate quality installations.

Objective 1: Enhance the quality of life of our people through continuous improvement in facilities, infrastructure, services and work environment to satisfy their needs and priorities.

Objective 2: Be a good neighbor by enhancing community relationships.

Objective 3: Demonstrate environmental leadership through proper planning and execution of restoration, compliance and hazardous waste disposal programs.

Both Human Centered Technology and Group Support Technology can be developed to support the AFMC's mission and help accomplish the objectives that spurred its creation. HCT provides a means to develop and produce superior weapon systems and logistics support, and GST provides the means to help support the partnership and integration aspects.

1. Integrated Weapon System Management

The cornerstone of AFMC's management and operational concepts will be Integrated Weapon System Management (IWSM). The objective is to provide a seamless weapon system organization—a single organization accountable across the life cycle of a weapon system. Thus, a single face will be presented to the operational commands and a clear line of authority and accountability to the user. The plan is to establish the Weapon System Program Office where it allows the centers (Product or Logistics) to concentrate on what they do best. For example, a new weapon system acquisition would establish a program office at the product center where it would remain until development is complete. The emphasis is on management continuity, not rapid transfer. Initially, physical moves of key personnel, e.g., the System Program Director, were contemplated as different phases in the weapon system life cycle occurred. As the IWSM concept matures, physical transfers may be less frequent as product and logistics centers focus on their areas of expertise. Ideally, a robust and broad-based matrix system could carry out many tasks without being collocated in the weapon system program office and avoid developing unnecessary internal capability in numerous organizations or offices.

The focus here is on creating an integrated program team with management continuity instead of a confrontation process between separate acquisition and logistics functions.[3] The systems engineering team under IWSM will use an Integrated Product Development (IPD) approach, and the Engineering Directorate of the new organization will be responsible for the integrated technical support for the IWSM concept.

2. Improved Business Practices

In applying Total Quality Management (TQM) to their planning, the AFMC planners have identified eight key processes of the AFMC:

- Systems engineering and configuration
- Requirements
- Finance
- Technology insertion
- Test and evaluation
- Contracting
- Logistics
- Program management.

In addition to IWSM, the planners for AFMC have identified opportunities for improved business practices in major acquisition areas. One of these areas is environmental management, in which the objective is to establish improved business practices that will respond aggressively to environmental challenges. This AFMC environmental team will include the following organizations and responsibilities: Engineering (EN), which will manage the technology transfer impact of hazardous materials (HAZMAT); the Surgeon General (SG) for safety and occupational health issues; and Science and Technology (ST), which will oversee technology opportunities. Because of HCT's potential applications to HAZMAT and safety issues, this development should be watched for opportunities.

[3] The focus has previously been on early transition of responsibility or a split in responsibility between Product Center to Logistics Center, often resulting in a confrontational process and precluding efficiency.

Additional areas of opportunity for the Acquisition Logistics R&D Activity include—

- Integrated functional processes across the eight key acquisition processes to enable the seamless organization.
- Integrated and expanded professional development and training.
- Integrated resource and facilities planning across the command.
- Expanded science and technology focus across the weapon system life cycle.
- Technology insertion across the total acquisition spectrum.
- Computer-Aided Logistics System development and implementation.
- IPD across program spectrum through IWSM.
- Communications and information systems focused in Communications and Computer Systems (SC) with consolidated standards and policy for AFMC systems.
- Extended Staff Support relationship with the Office of the Secretary of the Air Force (Acquisition) (SAF/AQ) with enhanced video conference capability.

3. Organizational Design

The proposed organizational structure of AFMC is shown in Figure II-1. The key organizations affected by the integration are Engineering (EN), Logistics (LG), Plans and Programs (XP), Requirements (XR), Communications and Computer Systems (SC) and Science and Technology (ST). All are standard Air Force offices except Science and Technology, which reflects AFMC's science and technology focus and which will execute the Technology Executive Officer (TEO) responsibilities. The organizations whose responsibilities are critical to the AFMC mission are as follows:

- Operations (DO)—All test, flight operations, and command and control.
- Logistics (LG)—Maintenance, supply and transportation, consistent with the Air Staff Structure.
- Science and Technology (ST)—Technology Executive Officer responsibility and single focus for technology across the life cycle.
- Plans and Programs (XP)—Command strategic plan, POM formation, manpower, and special studies.
- Requirements (XR)—Responsibility for all user requirements (systems to modifications to spares) and the IWSM.

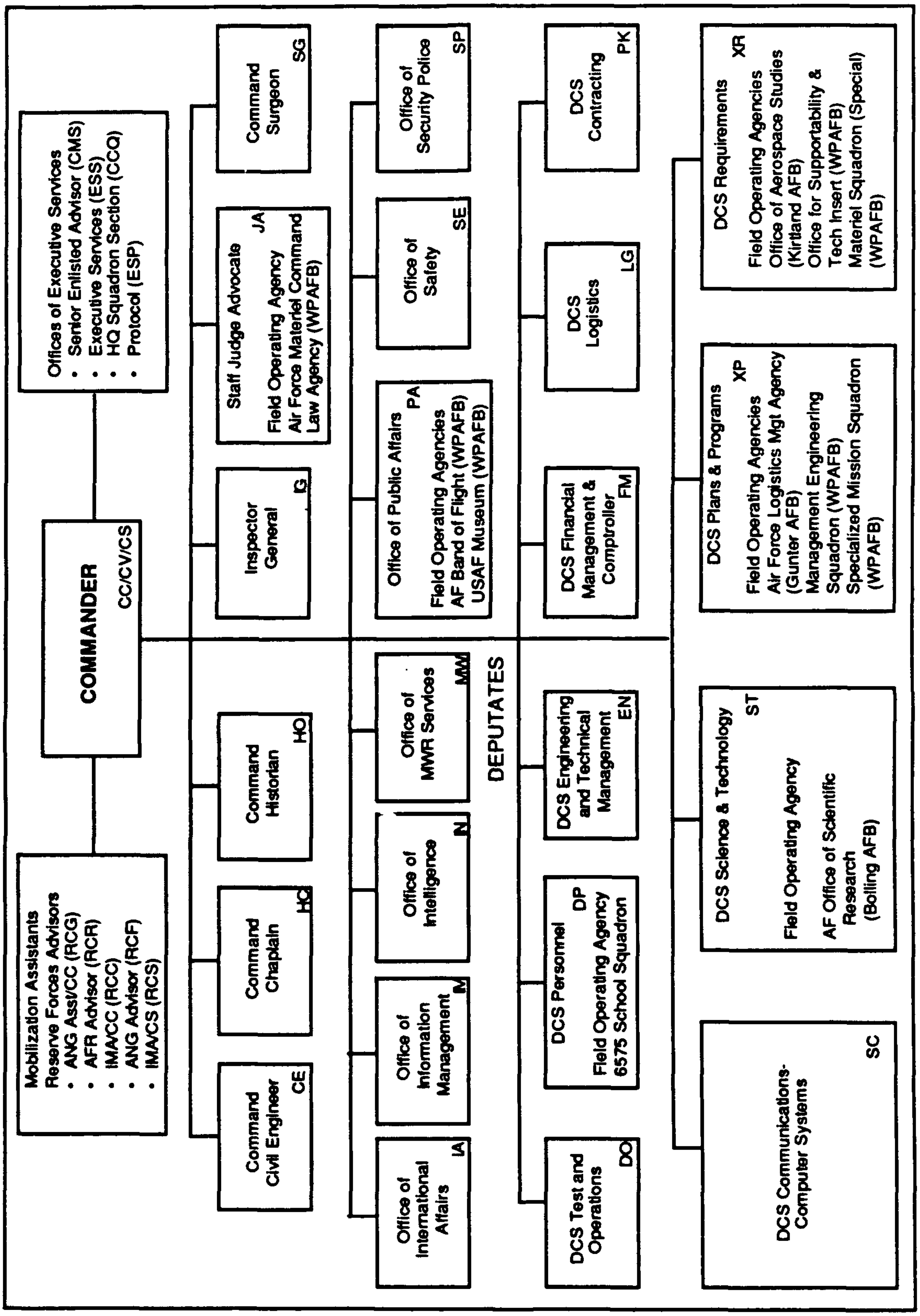

Figure II-1. HQ AFMC Structure

Engineering (EN) is the Headquarters focus for Industrial Base Management, with the objective of developing a consistent, integrated policy and providing a single face to industry for the implementation of acquisition policies. To improve industrial base management, Engineering will address 19 areas, such as planning and government/industry data sharing. Engineering is also responsible for Computer-Aided Acquisition and Logistics Support (CALS) and technical data. Significant cooperation is required among EN, ST, and SC in relation to CALS, communications and computer systems, and the manufacturing technology and other scientific activities in the laboratories. IPD responsibilities also rest with Engineering. Engineering, Logistics, and Requirements are consequential to the Acquisition Logistics R&D Activity's strategies.

The Acquisition Logistics Center is being disbanded, but its functions are being aligned at appropriate field or headquarters locations (see Section C.1, below). The Deputy Program Managers for Logistics (DPMLs) are being assigned to program offices.

The new AFMC will have 19 operating divisions. The five Air Logistics Centers (ALCs) are at Ogden, UT; Oklahoma City, OK; Sacramento, CA; San Antonio, TX; and Warner-Robins, GA. The four Product Centers (formerly the Product Divisions) are the Aeronautical Systems Center, Wright-Patterson AFB, OH; the Space Systems Center, Los Angeles AFB, CA; the Human Systems Center, Brooks AFB, TX; and the Electronic Systems Center, Hanscom AFB, MA. The start-up of AFMC should not result in major changes to the Logistics Centers, the four Product Centers, or the three Test Centers.[4, 5] Details on the Aeronautical Systems Center and the Oklahoma City Air Logistics Center, as specific customers for HCT and GST, can be found in Chapters III and V, respectively.

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4 The Direct Reporting Units, e.g., the Aerospace Guidance and Metrology Center for AFLC, are under review.

5 The people we visited with at the Oklahoma City Air Logistics Center generally felt that the formation of the AFMC will not affect the actual work of the ALCs, although there was some feeling that it would be easier to talk to people when everyone had the same boss (not having to communicate across Commands). Process Action Teams (PATs) have been formed at the ALCs to address the Air Force Logistics Command and Systems Command (AFLC/AFSC) merger, but they appear to have very little facilitator guidance, direction on what path to take, ideas of what to do, or even what questions to answer. They believe that creating the AFMC will be a very political battle—whoever has the most clout will keep their highest people, but the grass roots people will probably be left out of the decisions. The only guidelines given so far are that—

- There will not be a massive move of people.
- Functions may or may not be moved .
- There may or may not be a Program Manager (PM) at the Aeronautical Systems Center with a Deputy PM at an ALC or vice versa.

Reduced manpower projections for the combined Systems Command and Logistics Command (AFSC/AFLC) are 119,000 in FY96 versus 159,000 in FY86 and 137,000 in FY91. AFMC HQs will be smaller than combined AFSC and AFLC with 15 fewer organizations (22 versus 37). Staff projections are 2,360 for FY92 (down from 2,556 in Dec 1990) and 1,950 by the mid-1990s. All of these projections are subject to further refinement as DoD budgets are subject to revisions.

As it is now conceived, AFMC should be truly integrated in its organization and structure. In the key headquarters staff elements of Engineering (EN), Logistics (LG), Science and Technology (ST), Plans and Programs (XP), Requirements (XR), and Communications and Computer Systems (SC), the need for improved methods of communication, coordination, interaction, and shared data will be critical for AFMC to be effective in its reorganization. This need presents an opportunity for the Acquisition Logistics R&D Activity in the area of GST.

B. AIR FORCE LOGISTICS COMMAND MODIFICATION

The goal of the AFLC is combat readiness and sustainability, and its functions will be integrated into the AFMC to perform this part of the overall mission. This section contains information about the AFLC headquarters staff functions in particular because of their importance to the Acquisition Logistics R&D Activity and early restructuring to facilitate integration into its AFMC headquarters role.

1. Organizational Design

To increase its compatibility with the current organization of the Air Logistics Centers (ALCs)[6] and to facilitate its integration with the Air Force Systems Command (AFSC) into the Air Force Materiel Command (AFMC), the Air Force Logistics Command (AFLC) has undergone numerous changes. The AFLC is a large, complex organization that employs significant resources and a large number of computer systems, as illustrated in

6 See Chapter III, Section C.

Table II-1, which shows the size and scope of AFLC in 1990. AFLC is the third largest command of the 13 commands in the Air Force. Eleven percent of all people in the active Air Force are a part of AFLC. Five of the seven bases are the single largest employers at a single location in their respective states. AFLC's $158.3 billion in capital assets would rank it near the top of the Fortune 500 companies.[7]

Table II-1. AFLC in 1990

People	96,709
Capital Assets	$158.3B
Funds Managed	$50.3B
Annual Buys	$9.5B
Items Managed	961,516
Requisitions Processed	2.7M
Components Repaired	1,229,708
Aircraft Supported	20,779
Missiles Supported	1,147
Engines Supported	32,994
Logistics Management Information Systems	504

The previous functional divisions in the AFLC focused around Material Management (MM) and Maintenance (MA). MM had more white-collar engineering duties, and MA had the actual blue-collar shop duties. To provide focus in critical areas for the new organization, the Material Management (MM), Maintenance (MA), and the Distribution (DS) organizations have been disbanded and their responsibilities have been reassigned. The newly established Engineering (EN), Maintenance, Supply and Transportation (LG), and Requirements (XR) organizations will provide focus in these critical areas, and functional realignments have already been made in Financial Management, Engineering, and Requirements to consolidate responsibilities. Symbols have also been changed for consistency with AFSC in Contracting and Manufacturing and for the Comptroller Office.

EN at the AFMC will be the headquarters focus for IPD and, consequently, the target for HCT and GST support. This Deputate, the Deputy Chief of Staff for Engineering and Technical Management (EN), consists of the former Materiel Management

7 *Application for the President's Award for Quality and Productivity Improvement 1991*, Air Force Logistics Command.

directorates of Engineering and Technical Data and the Command Chief Scientist Office, as well as some positions from the former Maintenance organization and the Plans and Programs deputate. The purpose of the new Deputate is to develop policies and processes for the command's engineers and to guide implementation of technological advances into the logistics support environment. The new organization includes the following Directorates with their appropriate command functions:

- *Computer-Aided Acquisition and Logistics Support (CALS) and Technical Information* (ENC)—oversees the AFLC CALS program and develops policy for technical orders (TOs), engineering data, and automated data processing (ADP) requirements.
- *Engineering and Technical Infrastructure* (ENI)—provides planning for personnel development programs for AFLC engineers, engineering and technical planning, funding for engineering programs, management of various computerized logistics information systems and reliability and maintainability programs.
- *Manufacturing and Quality* (ENM)—oversees programs to ensure that quality is emphasized in AFLC engineering, manufacturing, and repair processes.
- *Systems Engineering* (ENS)—oversees development and measurement of all AFLC engineering processes. Its primary mission is to ensure integrated technical support for the Integrated Weapon System Management (IWSM) concept.

The Systems Engineering Directorate is further divided into a Process Integration Division (ENSP) and a Technology Application Division (ENST), and an Office of Engineering Administration also is included in the Deputate. As shown in Figure II-2, the Directorate comprises a total of 104 personnel—87 civilian and 17 military.

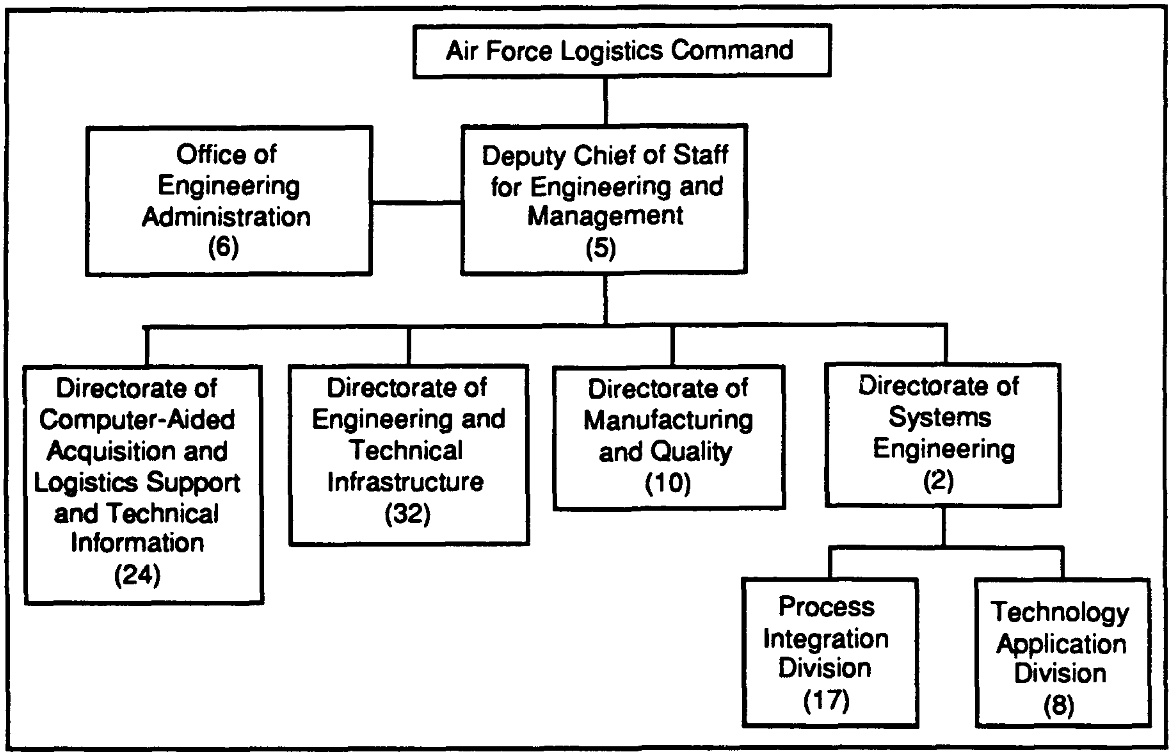

Figure II-2. The New AFLC Deputate for Engineering and Technical Management

2. Core Functions and Process Hierarchy

Associated with its TQM efforts and planning for the Logistics Management Systems, the AFLC in 1989 produced a document[8] outlining its functions, processes, and activities. In addition, the application by the AFLC for the President's Award for Quality and Productivity Improvement in 1991 further outlined the processes. The TQM efforts at AFLC, called QP4 for Quality, People, Process, Performance, and Product, relies on monthly video teleconferences with all command quality principles to be used to communicate the vision and QP4 values. Video teleconferencing is a type of GST, and success or lack of success in its use should be considered by the Acquisition Logistics R&D Activity to guide any GST development. More than 700 teams were used by the year 1991 in AFLC's TQM efforts. These teams included Process Action Teams (PATs), Quality Circles, and natural work groups.

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8 Air Force Logistics Command, *AFLC—Combat Strength Through Logistics, Logistics Management Systems*, 29 October 1990.

The core logistics functions were identified as Requirements, Acquisition, Distribution, and Maintenance. The functional activities under each of these core functions are shown in Table II-2. The activities under maintenance are related to those of the ALCs, as will be discussed in Chapter V. In addition to the core functions, the following logistics processes were also identified: Process Support, Requirements, Decision Support, Identification, Acquisition, Improvement, Plan/Program/Budget, Allocation, Custody, Movement, Accounting, Base/Command/Tenant Support, and Maintenance. Each of the core functions are included in this list except for Distribution, which is broken up into Allocation, Custody, and Movement processes.[9]

Table II-2. Activities of the Four Core Functions

Core Functions	Functional Activities
Requirements	• Generation of Buy/Repair Costs • Generation of Buy /Repair Quantities Recoverables, Bits and Pieces, Equipment
Acquisition	• Procurement • Contract Data Management • Acquisition :panning • Contract Definition • Initial Provisioning
Distribution	• Requisitioning • Inventory Control • Quality Control • Packaging and Preservation • Recoverables Management • Shipment Planning • Air/Surface Terminals
Maintenance	• Workload Planning • Scheduling • Material Control • Costing • Production • Contract Repair • Quality Assurance • Financial Management

9 The Distribution organization was ultimately dissolved and its duties reassigned around processes.

We have not seen a resolution or mapping of these 13 processes into the 8 critical processes identified for the AFMC, but assume that none of the processes have gone away.[10] The AFMC did not identify Decision Support as one of its processes, however, and this process appears to be a good target for GST support. These 13 processes can be arranged into a hierarchy as shown in Figure II-3.

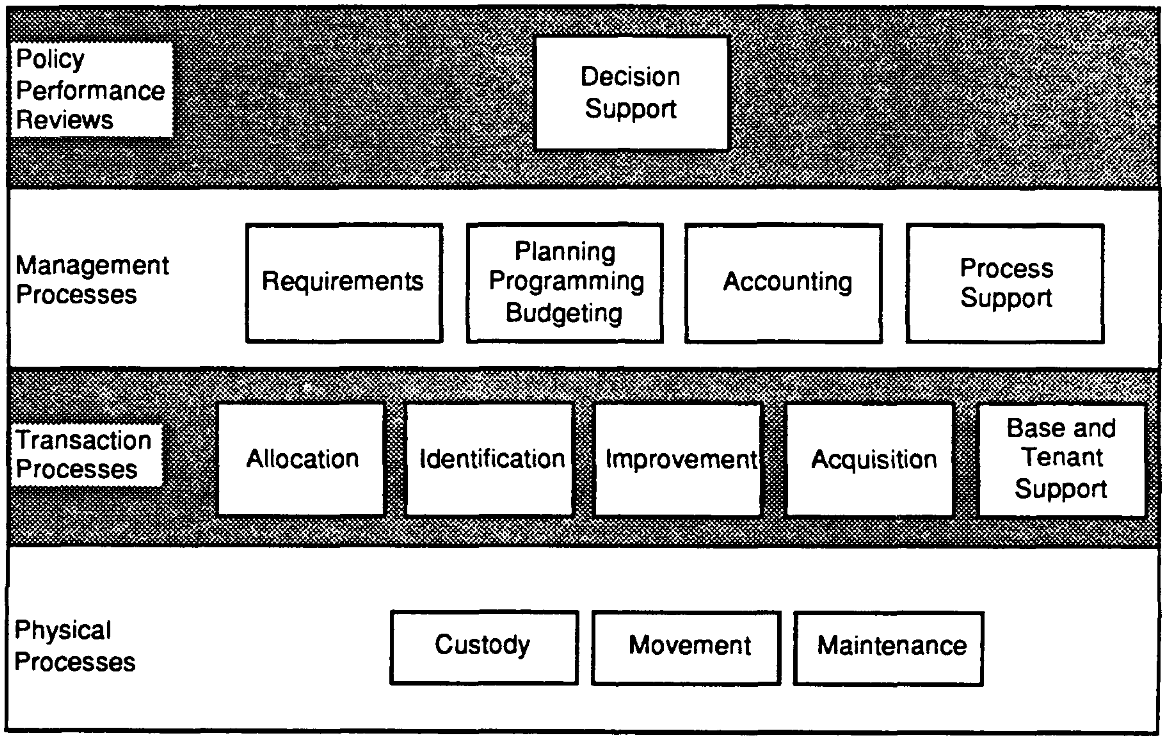

Figure II-3. The AFLC Process Hierarchy

The Decision Support process requires the assimilation of information from the operating level and base processes that support the weapon system logistics readiness and sustainability. Management decision tools, reviews, policy adjustments, and performance evaluations are required at this level to maintain the total logistics system. The customers or owners of these processes are the AFLC senior staff at the Headquarters, the Logistics Operations Center (LOC),[11] each of the Air Logistics Centers, and AF managers at all levels.

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10 The development of AFMC is an ongoing process, and these actions may very well be under consideration and evaluation.

11 The LOC no longer exists as a separate organization. Its functions are being assimilated into the new AFMC structure.

The management processes at the second level generate the information to serve as input to the Decision Support process. The Transaction processes initiate and control the hands-on activities, including requisitions, shipping and work orders, technical orders, and purchase orders. The Physical processes represent the actual hands-on action—the direct labor of warehousing, packaging, shipping, repairing, manufacturing, and modifying.

C. COMMUNICATIONS AND COMPUTER SYSTEMS

In conjunction with the integration planning for AFMC, a review of Communications and Computer Systems (C-CS) acquisition was undertaken. Today, there are three acquisition commands—AFSC, AFLC, and Air Force Communications Command (AFCC). There appears to be significant duplication of skills, technology, products, and customers between the three commands and the major commands (MAJCOMs). The acquisition of C-CS was found to be widely dispersed and in need of standardization, direction, oversight, and procedures.

Currently, AFLC, AFCC, and the MAJCOMs are involved in requirements, development, acquisition, operations, and support for C-CS. AFSC is involved in C-CS science and technology (S&T) as well as development and acquisition. In October 1990, AFCC's operational functions moved to the MAJCOMs, but the acquisition and support functions stayed. Since one objective of the new integration is to have a single acquisition command and a single acquisition process for all programs, the acquisition functions of AFCC are proposed to transfer to AFMC by January 1993. The C-CS programs would then be incorporated into the IWSM process development.

Under the proposed organization, all S&T, development, acquisition and acquisition-related support will be done in AFMC. AFMC may, however, provide some systems and support directly to the major commands (MAJCOMs), e.g., data collection intensive systems like the Reliability and Maintainability Information System (REMIS).[12] AFCC would continue its unique role in coordinating MAJCOM requirements, operating systems, and providing non-acquisition-related support. The goal is for all activities related to IWSM to be transferred to AFMC so that AFMC can accomplish a complete IWSM cradle-to-grave process.

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[12] More information about REMIS can be found in Section C.2, below.

This reorganization may be important to the Acquisition Logistics R&D Activity because of its necessary relationship with the Reliability and Maintainability Information System, REMIS (see Section C.2, below). REMIS/CAMS is one of the initial pilot programs now under AFCC that will be reassigned to AFSC/AFLC (AFMC) by 1 October 1991 and incorporated into the IWSM process development.

1. Center for Supportability and Technology Insertion

The former Acquisition Logistics Division of the Air Force Logistics Command began reorganization in September 1991 as the Center for Supportability and Technology Insertion (CSTI). One of the functions of this center (CSTI/AM) is to develop the Air Force Acquisition Model (AFAM), whose purpose is to improve the acquisition process and institutionalize a better way of doing business. It will provide the Program Manager (PM) and staff with information for planning, managing, and executing the program. It is intended to capture the IWSM process and be a vehicle for process improvements. AFAM customers will be the System Program Offices (SPOs), HQ AFMC, the Program Executive Officers (PEOs) and the System Acquisition Executives (SAEs), the Product Centers and Air Logistics Centers, and educational institutions. the SPOs will use the model as a planning and training tool to develop acquisition strategies, define strategies and schedules for program changes, challenge contractor inputs, and seek information on Best Practices. HQ AFMC will use the model analysis tools to establish a baseline for Acquisition Strategy Reviews, to define systemic problems and functional processes, and to accomplish process improvement. This activity is getting high-level attention in the Air Force, and the Commanding General of AFSC has said that he wants the Acquisition Process model, the first phase of the development, to be AFMC-wide by summer 1992.

CSTI is taking a phased approach to the development of the Acquisition Model. The first phase is a PERT chart of the acquisition process in a personal computer (PC) program called "Magic Eye." Individuals in the SPOs will use this tool when they write a document that plans a task. It will provide sample documents, empty outlines, excerpts from the regulations, expert opinions, and lessons learned.[13]

[13] We spoke with CSTI personnel about the process model. Although the model has been designed for individual use, the preparation of documents often involves more than one person. CSTI personnel expressed an interest in Groupware to have the capability of transferring and working on documents among a group of people.

CSTI's AFAM program requires coordination among the other commands (AFSC and Air Force Computer Command (AFCC)). Monthly video teleconferences are required with AFCC and biweekly teleconferences are required with AFSC. CSTI appears to be a potential customer for GST in the very near term and into the future both for the *process* of developing the Acquisition Model and for incorporating the capability into the model.

2. AFLC Information Management

For each of the 4 core logistics functions and their corresponding 13 logistics processes, a Logistics Management Systems (LMS) Modernization program was established to correct the deficiencies that users and planners identified. Computer systems that are in use or under development are shown in Table II-3. Those systems for the core functions are shown in italics. Some of the systems that may be pertinent to the work that the Acquisition Logistics R&D Activity does are described in the following paragraphs.

Table II-3. The AFLC Computer Systems[a]

Logistics Management Systems (LMS) Modernization Program
• *Requirements Data Bank (RDB)—Requirements function*
• *Contracting Data Management System (CDMS)—Acquisition function*
• *Stock Control and Distribution (SC&D)—Distribution function*
• *Depot Maintenance Management Information System (DMMIS)—Maintenance function*
• Weapon System Management Information System (WSMIS)
• Engineering Data Computer Assisted Retrieval System (EDCARS)
• Enhanced Transportation Automated Data System (ETADS)
• Intersite Gateway (ISG)
• Local Area Network (LAN)
AFLC Managed Air Force Programs
• Air Force Equipment Management System (AFEMS)
• Joint Uniformed Services Technical Information System (JUSTIS)[b]
• Reliability and Maintainability Information System (REMIS)
AFLC Initiatives
• Automated Technical Order System (ATOS)
• Central Procurement Accounting System (CPAS)

NOTE: Italics indicate systems for the core functions.

[a] Some or all of these systems can be affected by Corporate Information Management (CIM) decisions from a DoD perspective.

[b] JUSTIS has been disbanded as a program. Its functions are to be included in the Joint CALS (JCALS), which used to be the Army CALS (ACALS). Just how much of JUSTIS's functions will be included in JCALS is very dependent on which contractor gets the contract. The AFMC may have to modify or develop interim systems for ATOS or other functions depending on the functionality provided by JCALS and the time frames of their availability or operational capability.

The Automated Technical Order System (ATOS) automates the capture, creation, storage, and maintenance of technical order (TO) data changes. The digital technical order data is obtained by conversion of contractor-prepared digital data or by computer scanning of existing paper TOs. Automation of this process reduces resources required for the storage and handling of the paper TOs, and can greatly reduce the turn-around time for changes. The system has been fully operational since March 1987 with an upgrade accomplished in March 1990. All of the TO change generation and publication functions at the ALCs have been accomplished. ATOS requires information from contractors and the product management organizations at AFLC and the ALCs. It supplies TO change and update information and the Time Compliance TOs (TCTOs) to maintenance, repair, inspection, and modification functions (base level and ALCs).

The Reliability and Maintainability Information System (REMIS) will provide an automated system to receive, process, store, and retrieve performance information on Air Force (AF) weapon systems and equipment. It will be the primary AF data base for collecting and processing base, depot, and contractor maintenance and inspection information. REMIS can supply maintenance experience data to the AF contractors and receive the repair actions from them. It will provide managers access to reports for careful analysis of failure trends, excessive maintenance costs, quality problems and causes. REMIS is the primary source of Air Force Reliability and Maintainability (R&M) 2000 data. Its primary benefits are—

- to provide current visibility of weapon system status and availability.
- to expedite identification of required modifications.
- to provide improvements to R&M trend analysis and failure prediction techniques.

The Depot Maintenance Management Information System (DMMIS) is a work flow aid. It is being developed to integrate the management of depot repair functions, providing the maintenance engineer, planner, scheduler, parts expediter, manager, foreman, and accountant with the information required to accomplish their functions in a cohesive manner. Its goal is to provide for effective planning of all resources used by depot maintenance: facilities, manpower, tools, material equipment, funds. Its functions include long-range planning, production planning, production scheduling, material requirements

planning, resource capacity requirements planning, and execution support.[14] DMMIS will receive equipment history and edit tables from REMIS and will supply REMIS with maintenance actions. It is an extension of Manufacturing Resource Planning (MRP-II), but it is expanded and interfaced to provide just-in-time part supply. Grumman Data Systems has the contract for it, and the test bed is at Ogden ALC, Hill Air Force Base, UT. Phase I, Maintenance Material Control, is in place; Phase II, Maintenance Workload Control, Accounting, Planning, Standards, Tracking, Scheduling, and Quality Assurance, is scheduled for completion by late 1993.

The Engineering Data Computer Assisted Retrieval Systems (EDCARS) automates the requisitioning, indexing, filing, retrieval, and distribution of technical engineering drawings and specifications stored in a data repository. These drawings are used for provisioning, procurement, in-service engineering, maintenance, modifications, and manufacturing processes. Remote transmission of the digitized drawings provides engineers and maintenance technicians instant access to the data necessary to make major modification and repair decisions. EDCARS receives digitized engineering data drawings, standards, and specifications as part of the design and manufacturing process. Product management interacts with EDCARS for drawing revisions, engineering analysis, and modification design. Using EDCARS, maintenance functions have on-line access at a given site to engineering data to plan, analyze, and accomplish repair and modification of weapon systems and items. EDCARS became CALS-compliant in February 1991 with the capability to exchange raster digital data in compliance with MIL-STD-1840A (*Data Interchange File Management*) criteria.

Intrasite communications are accomplished through the Local Area Network (LAN) and the Central Processing Unit (CPU) Host-to-Host Network (HOSTNET). Intersite communications are accomplished through the Intersite Gateways (ISG) connections to the Defense Data Network (DDN) and the Defense Commercial Telecommunications Network (DCTN). Both of these would be important for any distributed GSS designed for ALC use. The LAN is located at each major AFLC installation, including all the ALCs, and it provides the medium to tie the various logistics programs together and make them accessible to users.

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14 Many of these functions are described in Chapter V, which elaborates on the Air Logistics Centers (Depots).

The AFLC Target Operating Environment (TOE) for Teleconferencing includes the seven-layer International Standards Organization (ISO) Open System Interconnection (OSI) model and the System Network Architecture (SNA) as designated software for TOE telecommunications. TOE systems support the Defense Digital Network (DDN) suite of protocols and are committed to support the OSI protocols when they are defined and adopted as DoD or Air Force standards.

To facilitate the use of, and maintain the efficiency and security for, all of the systems under the Logistics Management Systems, each AFLC base, including all the ALCs and headquarters at WPAFB, is building Logistical Systems Operations Centers (LSOCs). These central site information processing centers are huge facilities designed to enable the command to manage and perform its logistics mission. They may be prime targets for GST.[15]

3. Corporate Information Management

The development of C-CS, once consolidated under AFMC, will also have to occur in consonance with the DoD Corporate Information Management (CIM) initiative. The CIM initiative was the result of a Defense Management Report Decision (DMRD) to develop standard Automated Data Processing (ADP) systems across the Services and Defense agencies. The impetus for CIM is that current ADP systems are rarely designed using standard functional and common data requirements, resulting in multiple systems and software that meet the same functional requirements. The goal of CIM is to provide compatibility, eliminate redundancy, and develop consistent information requirements.

The Interim Standard Systems Component Working Group Report for the DoD Materiel Management Board chaired by DASD(Logistics)[16] identified the systems in Table II-4 as Logistics Interim Standard Systems for the Materiel Management and Distribution functions The Logistics Support Analysis Record (LSAR) was considered a de facto standard system because of its use as a standard for support data requirements under the CALS initiative. The other standard systems are the Joint Uniformed Services Technical Information Systems (JUSTIS) (now overtaken by JCALS); the Logistics Planning and Requirements Simplification System (LOGPARS), an ILS package being considered for

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[15] There is a major program entering acquisition to consolidate further the hardware and hosting of computer systems at each of the major LSOCs.

[16] Corporate Information Management, Materiel Management and Distribution, *Interim Systems and Executive Agent Selection Report*, Materiel Management Board, November 1990.

adoption by each of the Services; and the related packages for digitization of drawings and specifications information—the Navy's Engineering Data Management Information Control System (EDMICS), the Air Force's Engineering Data Computer Assisted Retrieval System (EDCARS), and the Army's Digital Storage and Retrieval Engineering Data System (DSREDS). Transition to the technologically superior EDMICS system by the Air Force and Army will be managed through the CALS initiative.

Table II-4. Computer Systems Identified for the Various Functions of Materiel Management Under Logistics[a]

Function	Systems
Acquisition Materiel Management (de facto Standard systems) Navy as executive agent	Logistics Support Analysis Record (LSAR) Joint Uniformed Services Technical Information System (JUSTIS) Logistics Planning and Requirements Simplification System (LOGPARS) Engineering Data Management Information and Control System (EDMICS)[b]
Requirements (Determination/Funding) Air Force as executive agent	Air Force Requirements Data Bank (RDB) competing with Army's Commodity Command Standard System (CCSS) because RDB will not be operational by October 1991.
Asset Management Requisition Processing/Distribution Management Maintenance Decisions/References/ Repairables Army as executive agent	Air Force Stock Control and Distribution (SC&D)

[a] DoD has recently established the Joint Logistics Systems Center (JLSC) at WPAFB. This organization is a joint Service, Defense Logistics Agency (DLA) and Office of the Secretary of Defense (OSD) activity and supersedes the CIM executive agent structure. The JLSC plans to manage computer systems from a DoD corporate view.

[b] Navy's improved version of the Air Force's Engineering Data Computer Assisted Retrieval System (EDCARS)

D. ONGOING ORGANIZATIONAL AND MANAGEMENT CHANGES

While we have focused on the reorganization of the AFLC and the merger of the AFSC into the new AFMC with the objective of a single acquisition organization within the Air Force, there are other reorganizations in the Air Force, the other Services, DLA, and OSD offices that can and will impact the structure and operation of AFMC. The impact of the new Air Combat and Air Mobility Command in the Air Force, combined with changes in the control and flow of appropriated money, is new and not yet fully understood. The prospects of increased Joint (Purple Suit) activities and the Defense Management Review (DMR) process, the establishment of the Joint Logistics Systems Center (JLSC), and the consolidation/centralization of resources management and policy at higher levels in the DoD all are uncharted areas for management and implementing activities. In this dynamically changing infrastructure, new relationships must develop. Human Centered Technology (HCT) and Group Support Technology (GST) will be prudent methodologies for application across a wide spectrum of activities as they unfold in AFMC and the AF.

III. PRODUCT CENTERS

Both the Product Centers and the Logistics Centers of the Air Force Materiel Command (AFMC) are potential customers of the Acquisition Logistics R&D Activity. This chapter discusses the Aeronautical Systems Division (ASD),[1] specifically the activities and functions of the System Program Offices (SPOs). The Manufacturing Technology Directorate of Wright Laboratory in the ASD is also discussed as a potential customer. The activities and functions of the Air Logistics Centers, particularly the Oklahoma City Air Logistics Center, is described in Chapter V.

A. NEW ACQUISITION CYCLE

Department of Defense Directive (DoDD) 5000.1, *Defense Acquisition*, and DoD Instruction (DoDI) 5000.2, *Defense Acquisition Management Policies and Procedures*, are the documents that give the guidance to the Program Executive Offices and the Program Managers and, hence, the SPOs in the Air Force.[2] Table III-1 contrasts the previous acquisition cycle phases and milestones with the new ones set out in DoDD 5000.1. Throughout this paper we will refer to the new names for the acquisition cycle phases.

These revised documents envision an *Integrated Management Framework* consisting of three systems: the Requirements Generation System, the Acquisition Management System, and the Planning, Programming, and Budgeting System. The disciplined approach for integrating the efforts and products of these systems requires—

- Translating operational needs into stable, affordable programs.
- Acquiring quality products.
- Organizing for efficiency and effectiveness.

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1 The divisions are not yet called Centers, so we will refer to ASD, as it is known. Consideration should also be given to the Space Systems Division as a customer for HCT, just as NASA is a customer for the JACK technology from University of Pennsylvania.

2 A supplement to the DoDD 5000.1 and DoDI 5000.2 specifically for the Air Force is in draft form and not available as of this writing.

Table III-1. Acquisition Milestones and Program Phases

Previous	New
Milestone 0, Mission Need Decision, *Program Initiation*	Milestone 0, Concept Studies Approval
Phase I, Concept Exploration /Definition	Phase 0, Concept Exploration and Definition
Milestone I, Concept Demonstration/Validation Decision	Milestone I, Concept Demonstration Approval, *Program Initiation*
Phase II, Concept Demonstration/Validation	Phase I, Demonstration and Validation
Milestone II, Full Scale Development	Milestone II, Development Approval
Phase III, Full Scale Development	Phase II, Engineering and Manufacturing Development
Milestone III, Full Rate Production Decision	Milestone III, Production Approval
Phase IV, Full Rate Production and Initial Deployment	Phase III, Production and Deployment
Phase V, Operations and Support (overlaps Phase IV)	Phase IV, Operations and Support (overlaps Phase III)
Milestone IV, Logistics Readiness and Support Review	Milestone IV, Major Modification Approval
Milestone V, Major Upgrade of System Replacement Decision	None

The process for acquiring quality products is to emphasize effective acquisition planning and improved communications with users using a concurrent engineering approach. At a minimum, Groupware could help with the improved communications, but its broader purpose is to improve the efficiency and effectiveness of a process that requires groups of people to work together. The new acquisition process with its integrated management should present many opportunities for Group Support Technology (GST) applications.

B. AERONAUTICAL SYSTEMS DIVISION

The Aeronautical Systems Division, located at Wright-Patterson Air Force Base (WPAFB), OH, employs about 8,000 people. Of this number, some 250 people are involved in long-range planning—planning for weapon systems 10 or more years out. The Development Planning Directorate (ASD/XR) under Mr. Jim Mattice is leading this effort.

He is also leading a strategic planning process to ensure compatibility of ASD with the new AFMC. When we last spoke the process had formed planning cells, each of which was to form teams to initiate the strategic planning. The goal is to develop a roadmap-like briefing. This sounds like an excellent opportunity for GST application and might easily be followed up by the Acquisition Logistics R&D Activity.

Thirty System Program Offices for aeronautical equipment are located at ASD, even though they may report directly to the Program Executive Officers (PEOs) at the Pentagon. The following sections describe the organization and activities of the SPOs.

1. System Program Offices

The main mission of a System Program Office is to deliver a product. The Air Staff issues a Program Management Directive (PMD) to the SPO, telling the SPO what has to be done. The direction on how to do it comes from DoDD 5000.1, *Defense Acquisition*, and DoD Instruction (DoDI) 5000.2, *Defense Acquisition Management Policies and Procedures*.

a. SPO Organization

Generally there are two types of SPO organizational structures (Figure III-1). First, there are generic, or "basket," SPOs that support several, similar programs using matrixed functional expertise dedicated partially or fully to the program depending on requirements. Often these types of SPOs are used for a new-start program in the concept phase. Examples of this type of organization are shown in Table III-2. This type of SPO has an overall SPO Director and individual program managers within the program reporting directly through the Program Executive Officer (PEO) chain for program specific direction. The smaller SPOs in the "basket" can vary in size from 25 to 100 people; the entire generic SPO may number 300 to 500 people.

The other type of SPO is a major program SPO used for larger programs, especially those entering Engineering and Manufacturing Development (EMD). These SPOs are autonomous organizations with dedicated staff where the Director reports directly to the PEO. Examples are shown in Table III-3. The "Projects" block of the Major Program SPOs in Figure III-1 is composed of project officers who are basically minor program managers within the program. As an example of size, the F-16 multinational program office had 350 people at its peak in the mid-1980s.

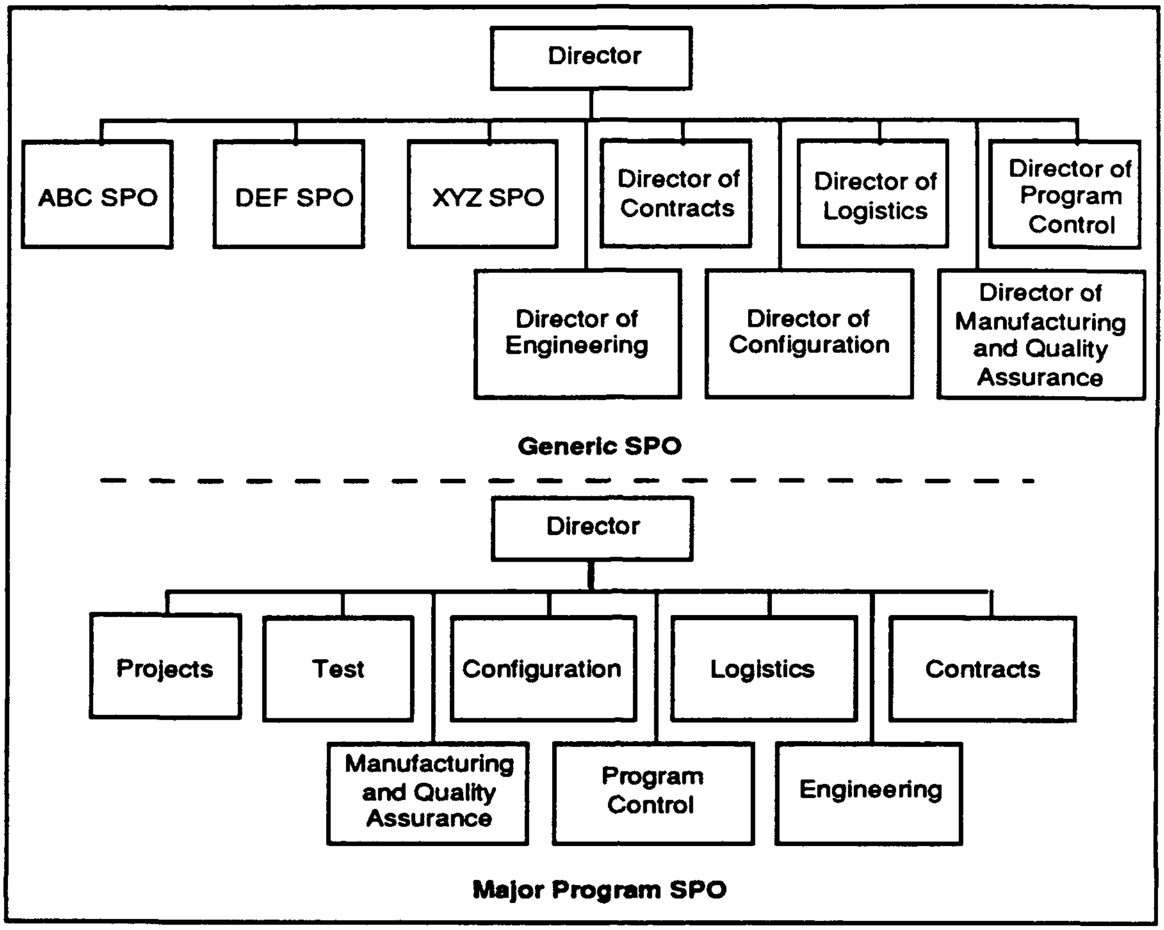

Figure III-1. The Different Types of SPO Organizations

Table III-2. The "Basket" SPOs

Basket SPOs	Location
Aeronautical Equipment SPO (which includes the PRAM and RAMTIP SPO)	Wright-Patterson AFB
Propulsion SPO	
Systems Program Office	
Training Systems Program Office	
Special Operations Forces SPO	
Flight Training SPO	
EC/Reconnaissance SPO	
Air to Surface Weapons SPO	Eglin AFB, FL
Joint Tactical Systems SPO	
Range Systems SPO	

Table III-3. Major Program SPOs

Major Program SPO	Program Executive Officer	Location
Advanced Tactical Fighter (ATF) SPO	Tactical Airlift Programs PEO	Wright-Patterson AFB, OH
F-16 SPO		
F-15 SPO		
C-17 SPO		
B-1B SPO	Strategic Systems SPO	
Advanced Cruise Missile SPO		
Short Range Attack Missile (SRAM) II SPO		
Small ICBM SPO		Norton AFB, CA
Peacekeeper Rail Garrison SPO		

b. SPO Activities

The functional areas included in DoDI 5000.2 are shown in Table III-4. The activities under Engineering and Manufacturing and Logistics and Other Infrastructure that may directly affect the Acquisition Logistics R&D Activity are further defined. The Human Systems Integration Section replaces DoD Directive 5000.53, *Manpower, Personnel, Training, and Safety (MPTS) in the Defense System Acquisition Process*. The Human Factors section is new.

Table III-4. Functions of the SPOs

- Requirements Evolution and Affordability
- Acquisition Planning and Risk Management
- Engineering and Manufacturing
  - Systems Engineering
  - Reliability and Maintainability
  - Human Factors
  - System Safety, Health Hazards, and Environmental Impact
  - Design for Manufacturing and Production
  - CALS
  - Quality
- Logistics and Other Infrastructure
  - Integrated Logistics Support
  - Human Systems Integration
- Test and Evaluation
- Configuration and Data Management
- Business Management and Contracts
- Program Control and Review

The Aeronautical Systems Center's new thrust for Engineering and Manufacturing Development (EMD) involves dedicated Project Action Teams (TQM concept) that will follow a development effort and be dedicated to it all the way through. These teams will include designers, manufacturing personnel, and logisticians. The ATF program is moving toward using this concept. The ATF program will also probably be the first to make Logistics Support Analysis (LSA) data available to the SPOs in a stand-alone data base as part of CITIS.

An observation made frequently in the context of the AFMC integrated organization is the relative lack of automation in the SPOs as compared with other organizational and functional elements of the AFMC.[3] This lack of automation must be considered a liability when considering the SPOs as potential customers for HCT and GST. However, we have been told that any technology that could reduce the time that SPO personnel spend in meetings would be warmly received. Thus, the SPOs appear to be good targets for GST for meeting support if the problems associated with computer usage (see Chapter VII) and the location of a Group Support System can be overcome.

2. Manufacturing Technology Directorate, Wright Laboratory

Wright Laboratory is one of the Air Force's new super laboratories (along with Armstrong Laboratory, of which the Acquisition Logistics R&D Activity is a part). It is composed of seven technology directorates, one of which is that Manufacturing Technology Directorate. Wright Laboratory serves as ASD's technology arm to provide technologies to the Aeronautical Systems Center's SPOs. Its customers are also the other product centers, AFLC, and occasionally the operational commands. The Concurrent Engineering Office with Mr. Jerry Shumaker is a part of this Directorate. Among its many projects, this office has been involved in the redesign of a brake pedal for the B-52 at the San Antonio Air Logistics Center (ALC).

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3 The Advanced Tactical Fighter (ATF) SPO may be an exception to this rule because it is such a new system and CAD data is available for it. The ATF SPO has already expressed an interest in HCT developed by the Acquisition Logistics R&D Activity.

Since much of the technology developed by Wright Laboratory is transferable to the civilian sector, a special office has been established to promote commercial uses as rapidly as possible—the Office of Research and Technology Applications (ORTA). This office assures technology transfer to state and local governments to promote rapid technology commercialization.[4] Currently ORTA interacts with the Federal Laboratory Consortium (national level), the Ohio Technology Transfer Organization (OTTO) (state level), the Technology Assistance Panel (TAP) (local Dayton level), and the Edison Materials Technology Center (state and local level). When Mr. Shumaker spoke at the U.S. Army/National Science Foundation Joint Symposium for the Technology Transfer of Concurrent Engineering Tools and Methodologies,[5] he stressed the importance of these organizations to his office's research and development. The R&D can reach not only the large defense and aerospace contractors, but medium- and small-size businesses in the commercial sector as well. They may also be important to work that the Acquisition Logistics R&D Activity does in the future.

Recently the Manufacturing Technology Directorate of Wright Laboratories, ASD, WPAFB, merged with the Industrial Base Division of the Directorate of Manufacturing and Quality of the Engineering Deputate at Air Force Systems Command (AFSC/ENMS). This combined office will be physically located at WPAFB, and the integration will take place under Dr. William Kessler. Because of the increased attention being given to support and maintenance of the industrial base due to the reduced procurement of weapon systems in the current austere budget environment, the importance of this office to the Air Force may be enhanced.

The Manufacturing Technology Directorate is a potential customer that could incorporate HCT for the human factors aspect of integrated information systems and the operability issues with shop floor process control command centers, as previously identified in the Acquisition Logistics R&D Activity's *HCT Draft Plan*. We have further identified the use of HCT for work station design and for use in analyzing the effect on shop floor personnel of introducing advanced manufacturing technology, with reference to

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4 Wright Laboratory Fact Sheet, 1991.

5 Huntsville, AL, 4-5 June 1991.

the ESPRIT project in Europe. The Manufacturing Science, or ManScience,[6] Program has as one of its elements the consideration of cultural and human factors. HCT and GST could be used for the human factors aspects of concurrent engineering or Integrated Product Development (IPD) and ManScience.[7]

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6 Manufacturing Science is that portion of the manufacturing technology program that deals with the basic principles and technologies used to characterize and improve aerospace manufacturing processes—both on and above the shop floor.

7 For applications of HCT and GST to manufacturing technology, the Acquisition Logistics R&D Activity should be aware of the new Manufacturing Technology Information Analysis Center (MTIAC) located at the IIT Research Institute, 10 West 35th Street, Chicago, IL, 312-567-4730.

IV. DEFENSE INDUSTRY

The defense industry (and industry in general) is an important potential customer for both Human Centered Technology (HCT) and Group Support Technology (GST), especially when applied to concurrent engineering. The information presented in this chapter was gathered on our site visit to General Dynamics (GD), Convair Division, in San Diego and accumulated over the last few years in our interactions with industry through our concurrent engineering research. Although much of what is said applies to the defense industry in general,[1] because this paper is for an Air Force laboratory, we focus on the aerospace industry.

Like most defense contractors, GD Convair is reducing personnel and resources. GD Convair has approximately 8,790 people, 1,600 of whom are in the engineering domain (through and including preparation for production). Engineering is decreasing in percentage of population, while blue collar production is increasing. This shift was not anticipated a few years ago. People responsible for their computer systems are also decreasing rapidly. The Information Resource Management (IRM) division previously had 30 people but now is down to 18. The Data Systems Division is being disbanded. The Integrated Management Systems (IMS) initiative has been reduced from 72 to 42 people, and we were told they would probably lose more in the future. They are operating on one-quarter of their capital budget: 2 years ago IMS had $10 million in capital budget; in 1990, it was down to $2.9 million. In the future, we expect the defense industry to reflect the DoD and the military in its decreasing resources and number of personnel.[2]

A. PRODUCT DEVELOPMENT PROCESS

The processes in the development of a weapon system, particularly but not exclusively in an aerospace company, can be categorized a follows:

- Requirements Definition

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1 Human Performance Models have also been used in the commercial sector, as we will discuss later.

2 Foreign military sales (FMS) and direct sales to foreign countries can help supplement the decreased DoD budget and keep some of the production lines alive.

- Product/Process Definition
  - Product definition
  - Manufacturing process definition
  - Support process definition
- Product Delivery
- Product Support

Under integrated product development (IPD), or concurrent engineering, the product definition is developed in parallel with the manufacturing process and support process definitions by a multifunctional product development team. Although traditionally used for operation or support process definition and design influences, we believe HCT could be used in both the support and manufacturing process definitions.

1. Design Phases

The traditional phases of design, or product definition are conceptual design, preliminary design, and detailed design. These phases are also required in integrated product and process definition, or concurrent engineering, as the process of design moves down through the physical hierarchy of the product and more and more detail is defined. There is an effort, however, to move specific activities up front in the process as much as possible to facilitate the manufacturing and support process definition.

a. Conceptual Design

The first step in weapon system design and development is conceptual design. During this phase a functional needs analysis is done, system operational or functional requirements are defined, and the system maintenance concept is developed.

b. Preliminary Design

The preliminary design phase includes the processes of functional analysis and requirements allocation, trade-off studies and optimization, and detailed specifications. Emphasis during this place is on exploring all the possible alternatives that could be designed to meet each function and then integrating the chosen alternatives.

c. Detailed Design

The detailed design phase involves the description of subsystems, units, assemblies, lower-level components, and elements of logistics support (e.g., test and support equipment (SE), facilities, personnel and training, technical data, and spare/repair parts). This phase also includes the test and evaluation of a prototype model. It is during this stage that computer-aided design (CAD) is most useful.[3]

2. Specialty Engineering Functions[4]

The functions or disciplines involved in product and process definition include reliability, maintainability, testability, human factors engineering, producibility, and safety. MIL-STD-488, *Systems Engineering*, has been recently revised to ensure that these disciplines are addressed in an integrated approach consistent with concurrent engineering. The goal of this process in the defense industry is to ensure that the weapon system produced will continually perform its intended mission or be available to perform its mission when needed while maintaining a balance of system performance, schedule, and cost.

The disciplines of maintainability, human factors engineering, producibility, and safety are pertinent to our discussion of applications of HCT. Thus, they are addressed more fully here.

a. Maintainability

The efforts of maintainability engineers are focused on making weapon systems as easy and inexpensive to repair and maintain as possible. The goals of maintainability engineers are to make sure the product design allows faults to be easily identified, requires minimum manpower and logistics support resources to repair the faults, and enables the

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[3] GD Convair notes that the fact that CAD is used so late in the process explains why early projections of the benefits of CAD have not been realized.

[4] James V. Jones, *Engineering Design: Reliability, Maintainability and Testability*, TAB Professional and Reference Books, Blue Ridge Summit, PA, 1988.

Benjamin S. Blanchard and Wolter J. Fabrycky, *Systems Engineering and Analysis*, Prentice Hall, Inc., Engelwood Cliffs, NJ, 1981.

Additional information in this section on the Logistics Support Analysis/Logistics Support Analysis Record (LSA/LSAR) was provided by Ed Boyle, Armstrong Laboratory, Human Resources Division, Logistics Research Branch, WPAFB, in a paper he provided, titled *The New LSAR: A Trip Report*.

regularly scheduled maintenance for overhaul to be efficiently and effectively accomplished. The tools of the maintainability engineers include modeling, allocation, prediction, and testing.

MIL-STD-470, *Maintainability Programs for Systems and Equipment*, describes the methods to be used during the Maintainability Program. The tasks include Program Surveillance and Control, under which the maintenance concept is described in the maintainability program plan, Design and Analysis, and Evaluation and Test. Under Design and Analysis, the Failure Modes Effects and Criticality Analysis (FMECA) is performed to develop and document maintainability information. The FMECA will form the basis for defining many other logistics-related requirements for the equipment. Maintainability analysis is performed and design criteria developed under this second task. Inputs to the analyses come from reliability, human factors engineering, safety, and testability analyses and maintenance planning. The information needed from the human factors engineering includes that of recommended skill levels and quantities of maintenance personnel. The design criteria evolved in this process address issues of accessibility and required tools and procedures, all of which can be facilitated by the use of Human Centered Technology (HCT).

It is also during the Design and Analysis task that the prediction of the maintenance resource requirements such as the personnel and training requirements, the test and support equipment requirements, and the supply support is part of the analysis. Inputs are developed for the Detailed Maintenance Plan and the Logistics Support Analysis (LSA), both of which can be facilitated by the design documentation role envisioned for HCT.

During Evaluation and Test, the maintainability demonstration is planned and conducted. The demonstration is conducted using the actual equipment, technical orders (TOs), and support equipment (SE) that have been specified for the weapon system. This validation and verification process and its relationship to the Air Logistics Centers (ALCs) is described in Chapter V, Section A.3.

b. Human Engineering

The goal of human engineering is to optimize the human-machine interface for both operation and support of the equipment, and it is with this discipline that HCT is most closely aligned. MIL-STD-1472C, *Human-Engineering Design Criteria for Military*

Systems, Equipment, and Facilities, and the specification MIL-H-46855-B, *Human Engineering Requirements for Military Systems, Equipment and Facilities*, contain the requirements for the inclusion of human engineering in the acquisition process.

The human factors requirements come from the operational requirements and the system maintenance concept described during conceptual design. Through a functional analysis the operational and maintenance functions are then defined. The functions are further split and distributed into a hierarchy of job operation, duty, task, subtask, and task element.

The human tasks necessary to operate and maintain the equipment have to be developed with information from the reliability, maintainability, maintenance planning, and safety analyses. These tasks previously began at the time of the FMECA and continued until the final technical documentation was produced. The goal of concurrent engineering, however, is to move this type of analysis to as early a design stage as possible. Through the use of physical mock-ups, models, and simulation, the human engineer can develop the design alternatives that best serve the human-machine interface. Now with soft prototyping and simulation, HCT is the type of technology that can enhance the efficiency and effectiveness of this process.

Human factors data and human engineering areas of concern are shown in Tables IV-1 and IV-2.[5] The design considerations for human engineering that include these areas of concern and data are addressed in the areas of controls and displays, environment, anthropometry, work space, maintainability, and labeling. HCT as conceived by the Acquisition Logistics R&D Activity (computational human factors) can be applied in all these areas.

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5 Taken from James V. Jones, *Engineering Design: Reliability, Maintainability and Testability*, TAB Professional and Reference Books, Blue Ridge summit, PA, 1988.

Table IV-1. Human Factors Data

Item	Description
Environment	Location and condition of work environment.
Space	Amount of space required to perform task. Amount of space available. Body movements required to perform task.
Information	Amount of information available to operator. Amount of information required to perform task.
Time	Amount of time allocated for task completion. Frequency of task performance. Maximum allowable time for task completion.
Resources	Number of personnel required to perform task. Tools and other equipment required. Instructions and manuals required.
Other	Safety hazards. Interaction required between crew members. Personnel performance limitations. Equipment performance limitations.

Table IV-2 Human Engineering Areas of Concern

- Physical man-to-machine interface (physical, aural, visual)
- Physical man-to-man interface (physical, aural, visual)
- Physical comfort of operator/maintenance personnel
- Equipment-handling requirements (weight, cube)
- Temperature, humidity, etc., to be encountered
- Inclement conditions (rain, snow, mud) anticipated
- Climate (arctic, desert)
- Equipment environment (vibration, noise)
- Usable space availability
- Effects of special clothing (gloves, NBC, coat)
- Safety and hazard protection
- Mission-related requirements (tactical environment)

c. Producibility

The producibility of a system or equipment design refers to its inherent characteristics that enable the most effective and economic means of fabrication, assembly, inspection, test, installation, and acceptance. Producibility analysis aids in the integration of the product definition and the manufacturing process definition. Although all the areas addressed by producibility engineers are not related to HCT, the manufacturing operations that involve human interaction certainly do—there is a direct relationship between maintenance that requires disassembly and production that requires assembly.

When we visited GD Convair, we were told that their application of HCT, Supportability Analysis WorkStation (SAWS), was used by the Advanced Cruise Missile (ACM) program to determine fuel line installation questions. This was a time-critical design procedure, and within one-half week the ACM team was able to arrive at a prioritization of design alternatives. The issues involved accessibility of the manual assembler of the fuel line and the type of connector that could be used.

In developing the production plan, other topics that surface and are also needed for logistics support types of analyses are manpower, resources, and training requirements. The production documentation has to include every step and function to assemble the system. Again, the overlapping types of problems that need to be solved are opportunities for HCT.

d. System Safety

The system safety objective is to influence the product definition so that resultant equipment is as safe as possible to operate and maintain. Safety issues, then, involve the human-machine interface in relation to hazardous substances, components, operations, location of equipment, and risks caused by human error. The opportunity here is for HCT to be used to develop the hazard assessment matrix and the System Safety Program Plan (defined in MIL-STD-882B, *System Safety Program Requirements*).

e. Supportability

Design for supportability must consider the factors associated with the maintenance of the system, plus the supporting resources of spare and repair parts, the support equipment (SE) and test equipment, the personnel, facilities, training, and the packaging, handling, storage, and transportation of the system and its spare parts. The maintenance planning begins with the definition of the maintenance concept and continues through the

logistics support analysis during design and development. The logistics support requirements for military systems, including the human-centered ones, are estimated during this process through a procedure called Logistics Support Analysis (LSA) (MIL-STD-1388-1A, *Logistics Support Analysis*). Results of this analysis are recorded using data formats shown in detail in MIL-STD-1388-2A [*DoD Requirements for a Logistics Support Analysis Record* (LSAR)]. It has been estimated that about 80 percent of all LSAR data requirements involve measurements or judgments about human performance at some level. One objective of LSA/LSAR is to provide a structured way for supportability issues to influence equipment design. Another objective is to define requirements for the various elements of system support. These elements include maintenance manpower and personnel, training, training equipment, and technical data,.

The human-centered LSA/LSAR elements for equipment maintenance correspond to the standard human engineering requirements in military acquisition. Task analysis, workload analysis, and dynamic simulation are three important tools for evaluating the human/machine interface called out specifically in MIL-H-46855B, *Human Engineering Requirements for Military Systems, Equipment, and Facilities*. The LSA and human factors engineering (HFE) standards are, in fact, cross-referenced. HFE fits under the logistics element called Design Interface. For typical maintenance tasks on military systems, there is little point in distinguishing HFE criteria from LSA data requirements. For example, LSA Task 401, Task Analysis, specifies a number of maintenance HFE task criteria. These include procedural steps required to perform the task, task frequency, difficulty, crew size, personnel skill level and job specialty required, safety hazards, and repair times, among others.

3. Design Documentation

Design documentation is required to provide the information necessary both to manufacture the equipment (engineering drawings) and to operate and support the equipment once it has been deployed. Information for the operation and maintenance of the system is contained in the technical manuals or orders (TOs). MIL-M-63036A, *Preparation of Operator's Technical Manual*, gives detailed requirements for the preparation of the Operator's TO, which must include instructions for operating and maintaining the system, the lists of support equipment, and other reference material. Maintenance manuals are usually more technical than the operator's manual and generally contain much more information.

The traditional way of documenting the maintenance tasks, especially for critical maintenance tasks, is through task analysis using physical mock-ups or expert judgment based on verbal task descriptions. In this regard, see also LSA Report 006, "Critical Maintenance Task Summary," and the LSAR "B" Data Record, "Criticality and Maintainability Analysis."

The "C" Data Record called "Operation and Maintenance Task Summary" consolidates the operations and maintenance tasks identified for each repairable equipment item. It is used to record support requirements such as tools, facilities, and training equipment. The "D" Data Record "Operation and Maintenance Task Analysis" requires detailed, step-by-step information on how tasks should be performed, the applicable task performance time, and the job specialist [or Air Force Specialty Code (AFSC)] required. These data become vital inputs for the development of maintenance technical data and the definition of personnel requirements for system support. Increasingly, they are inputs to "downstream" maintenance manpower and training planning requirements estimation. HCT should allow human/machine integration issues to be visualized, and allow task analysis to begin earlier and end more accurately than it does now. Additional LSAR data requirements that might be satisfied by HCT are "Personnel and Support Requirements" (Data Record D1), "Support Equipment or Training Material Description and Justification" (Data Record E), and "Skill Evaluation and Justification" (Data Record G).

B. ENGINEERING TOTAL QUALITY MANAGEMENT

At GD Convair we spoke with the Director of Engineering Total Quality Management, who explained that a management team is charting the development process and developing guidelines for IPD teams and team leaders. This team is using DoDD 5000.1 and DoDI 5000.2 to determine metrics and exit criteria to be included in the guidelines. After working over a period of 3 months, all seven divisions of GD were going to meet—this is a serious enterprise-wide effort. GST could support these activities as well as the strategic planning activities among management.

Although resources are required to initiate the IPD process, GD does expect to see some cost savings. They estimate at best a 5 percent cost savings in concept development but a 35 to 40 percent reduction in Engineering and Manufacturing Development and Production. All of the plans and procedures for Engineering Total Quality Management have been developed on pure indirect funds—out of their bottom line.

GD Convair's strategy for IPD requires top management commitment and development of three enabling elements: computer-based support tools, multi-disciplined product development teams, and formal methods. The computer-based support tools are discussed in Section D of this chapter. This section will discuss the IPD teams. The formal methods that GD proposes to support their IPD teams include—

- Requirements Driven Design and QFD[6]
- Work Process Redesign
- Robust Design (Taguchi)
- Part Reduction
- Design for Assembly
- Statistical Process Control (SPC)
- Activity Based Accounting Practices.

While at GD Convair, we viewed a videotape that outlined their new product development process. Like other enterprises, GD Convair was a highly fragmented organization in the past. Each functional organization acted like a company in itself with its own internal data bases, inhibiting horizontal or lateral communication. The new process was demonstrated with the design of a bulkhead. First, the product development team members consulted with the customer to ensure that their design would meet the customer's requirements. A functional analysis was then done using block diagrams, and three-dimensional Euclid[7] models were built from the block diagrams of the requirements. Detailed parts and the design were further developed and then transferred to the producibility, stress analysis, and reliability and maintainability groups and to other specialty functions. The electronics group received a general space allocation from the structural designer and then commenced the electronics design. The design underwent electronic proofing (using the computer models instead of a hard mock-up) and then was released to the Numerical Control (NC) programming personnel for the programming of the robotic manufacturing equipment.

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6 QFD is actually not used yet because GD Convair has no customer support for it. They need a requirements document for QFD.

7 Euclid is the 3-dimensional Solid Modeling software package that GD Convair has been using for the past 24 months. Euclid is also used at Wright Patterson AFB.

The presentation stressed that although this is a team process, the designer maintains configuration control for the design at all times. The designer has to have the ultimate control and should begin configuration control as early as the proposal stage, in Conceptual Design. Specialty engineers retrieve the design from the designer's CAD data base as an object—they do not change the designer's original object, but save it under a new name to make changes and do their analysis with their own functional software. The designer can then be notified over the computer screen (if the capability exists) or on E-mail with suggested changes. The designer always has the ultimate release authority.

Previously, specialty engineers always gave a yes or no answer to the suitability of the design in their specialty area—they had no time or ability to suggest changes. Now they function in a problem-solving mode, like a designer, because the computer tools allow for the rapid interaction between functions.

GD Convair is instituting four levels of release of the design based on the degree of confidence that the authors have in the data:

1. Designer release
2. Design team release
3. Release for limited procurement
4. Prototype/manufacture release (traditional)

The first level is to be very informal and allow many changes as the design concept develops. All IPD team members will have access to the design, which will be identified by file version or revision. The second level will require a more mature design or data package that is ready for review and comment. The third level will be invoked as the design becomes stable and will permit the manufacturing process planning and validation of tooling design. The fourth level will be achieved after the validation of the complete product definition package and will be known as the enterprise release. This release will be the product baseline, subject to formal change management. This last release is the traditional release in the old way of doing business. Northrop has a similar procedure that it calls "phased parallel release." The idea is that production and supply can gear up before the final release of the design, thereby cutting cycle time.

1. Integrated Product Development Teams[8]

In keeping with the "team of teams" concept described in *Concurrent Engineering Teams*,[9] GD Convair has a structure that involves Product Development Teams (PDTs), formed around the work breakdown structure, and a Program Integration Team (PIT) composed of the team leaders of all the product development teams and the Program Manager. The Program Integration Team leader is the person previously known as the chief engineer and is selected by the Program Manager. The PIT team leader decides what the general teams are, selects the team members, and tries to arrive at consensus with the team.

This process requires the chief engineer to give up some responsibility and the team to accept it. Training in the areas of team and leader skills, formal methods, and computer-based tools is essential for this process to work. Such training is expected to require lots of money; however, the current capital budget for it is only one-quarter of the average over the previous 5 years:

> Training represents the largest proportion of cost even at a time of stability; now at a time of widespread change at Convair, training and later retraining can be incredibly expensive. Training costs can be reduced by providing a consistent, easy-to-understand user interface common to all software tools and computer platforms.[10]

The PDT team leaders are selected by the Program Manager in coordination with the functional management and the PIT team leader. The PDTs have both full-time core team members that represent the critical functions of design, manufacturing, and support and part time members whose efforts are not required on a full-time basis. All of the team members are expected to remain with the team throughout the development process and into production. Supplier integration is also an element of the PDT teams. GD Convair is using electronic communications to improve supplier coordination (integrated text and graphics transmission) and is even trying to get the partner selection process to include consideration of electronic communication capability. The problem again is the legacy

8 The detailed information about GD Convair is taken from their *Integrated Product Development Practices for General Dynamics, Convair Division*, 19 March 1991, received from Dr. Rick Brusch on our site visit.

9 David A. Dierolf and Karen J. Richter, *Concurrent Engineering Teams*, IDA Paper P-2516, Volume I: Main Text and Volume II: Annotated Bibliography, November 1990.

10 Craig McGinnis and Richard Brusch, "Convair Goes Concurrent," *Computer-Aided Engineering*, February 1991.

systems and the varying supplier capabilities, which may vary from drafting to wire frame modeling to 3-D solid modeling. The primary function of the PIT is to act as the integrating agent for all the PDTs to ensure that the overall system design and interface requirements are being met and the program is proceeding according to the program plan.

2. Team Meetings and Product Reviews

The multifunctional product development teams in concurrent engineering accomplish much of their work through formal and informal reviews and meetings.[11] To be effective, each individual team member's work must be accomplished outside the meetings, and the meeting time reserved for problem solving and decision making. Minutes of the meetings must be recorded and distributed to all relevant players in the organization, and the design decision rationale must be documented. These activities could all be supported and enhanced through group support technology (GST).

At GD Convair, the different types and levels of meetings include:

- Informal day-to-day interactions between team members.
- Intra-PDT meetings to address team actions.
- Inter-PDT meetings to address configuration item interfaces.
- Functional peer reviews.
- Subcontractor item reviews.
- Product Development Review Board (PRDB) meetings that review the design and process prior to level 3 and level 4 release.
- Formal contractual design review for the customer.

The intra-PDT meetings are to occur frequently to determine the status of the development effort and to exchange information. Minutes of the team meetings are to be kept, published, and distributed to all full- and part-time team members after each meeting. Team records, to be kept by the team leader, include a team roster, the team development strategy, schedules, resource allocations, copies of all minutes, data descriptions and locations developed by the team, and a list of the ground rules, assumptions, and requirements used by the team for product development.

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[11] Dierolf and Richter, *Concurrent Engineering Teams.*

Inter-PDT reviews are informal meetings that coordinate design changes with all affected PDTs with design interfaces to the configuration item. Team records to be maintained by each team leader include the inter-PDT meeting notes, meeting action items and status, and a list of the ground rules.

In its IPD Guidelines, GD Convair states that communication is a key element of the PDT process.[12] The chairperson of each review is to publish the review minutes, which will be distributed, at a minimum, to the full- and part-time team members of the PDT holding the review and all other pertinent persons. The minutes are to include, at a minimum—

- The agenda
- The list of attendees
- Copies of all handouts
- A facsimile of all board presentations
- Comments on all significant decisions made during the meeting
- A list of all action items with the assignees and the current status
- A list of all decisions and the basis for each decision.

The detail required and the amount of time required to assemble and distribute these items makes IPD meeting and review support an ideal candidate for GST for meeting support.

C. INTEGRATED MANAGEMENT SYSTEM[13]

While at GD Convair we talked with the program director of the Integrated Management System (IMS). The spirit of IMS is embedded in TQM, which encourages teamwork, trust, and the quest for continuous improvement.[14] The IMS function is to plan, develop, and implement improvements to the business process relating to GD Convair's IPD effort. The IMS team deals with standard practices and procedures, and the goal of the system is to make all the required information readily available to the IPD teams when the design is being done. This is accomplished by a single, common, shared Product

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12 *Integrated Product Development Practices for General Dynamics, Convair Division*, 19 March 1991.

13 The information in this section was derived not only from our conversations with Dr. Richard G. Brusch but also from the viewgraphs of the Strategic Assessment of Information Systems Review, 21 June 1990, provided by Dr. Brusch.

14 McGinnis and Brusch, "Convair Goes Concurrent."

Definition Data Base (PDDB) that spans the product life cycle and allows the cross-functional configuration management and communication across the enterprise. The PDDB is to provide decision histories, engineering notebooks, interrelationships of information, traceability to source documents, and trade studies documentation. It offers a way to track the change traffic. Digital Equipment Corporation (DEC) is acting as the system integrator and is developing commercial software that will be key to IMS.

The computer-based support tools to accomplish this new vision include—

- "Framework" for Integration
- Shared Information
- Enterprise Master Planning
- Solid Modeling
- Networked Teams (including suppliers)
- Simulation
- Applications Tool Set.

Solid modeling provides communication of the structural and mechanical design concepts earlier in the design process than CAD and allows electronic mock-ups to identify tolerance and fit problems early, before the costly physical mock-ups (Figure IV-1).[15] McGinnis and Brusch ascribe the following advantages to solid modeling:

> Solid modeling provides a more natural understanding of proposed designs for all team members and makes it easier to discover the relationships among systems, structures, materials, and processes. Moreover, a solid model offers an unambiguous definition of the geometry and topology, simplifies computation of physical properties, enables detection of interferences, and supports determination of dimensions and tolerances.[16]

Matra Division, Inc., is working with DEC to apply its Euclid-IS Solid Modeling system in IMS.

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[15] GD Convair attributes some of the lack of promised success from CAD and CAM systems to the fact that they cannot be used until the Detailed Design phase.

[16] McGinnis and Brusch, "Convair Goes Concurrent."

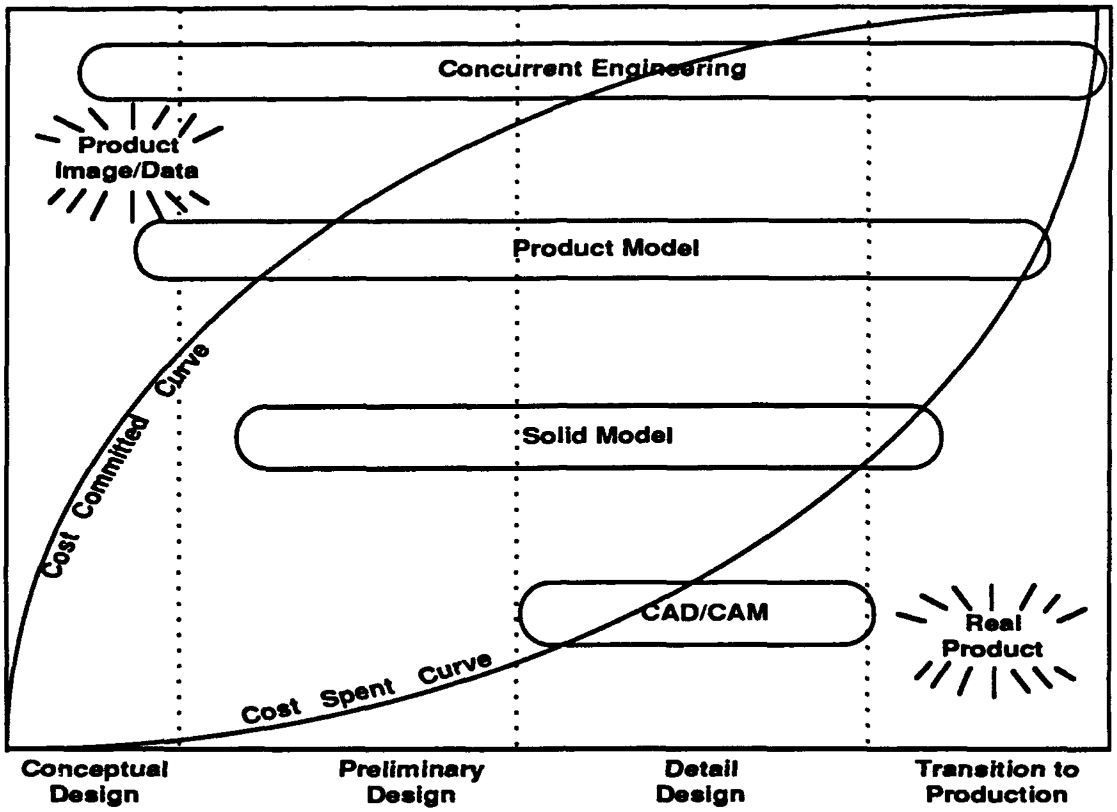

Figure IV-I. Use of CAD and Solid Modeling in the Stages of Understanding

Enterprise Master Planning provides task and program planning tools and allows identification of resource conflicts.[17] The framework provides product data and work process flow management and the transparent integration of application tools. The data base must be logically integrated and physically distributed and must include a data dictionary and allow transparent data sharing. Networks of powerful desktop workstations, a common user interface, portability of applications between heterogeneous platforms, and transparent data exchange between application tools all allow for the fast iteration in the design process required by IPD. Adoption of national and international standards will enable much of this integration. This new process is being designed to meet their customer needs for electronic data transfer of geometry and text, configuration management, maintenance manuals, and technical data.

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[17] Project/2, developed by Product Software Development, Inc. (PDSI), is the enterprise-level tool, Clarris Corporation's Quicknet is the program-level scheduler, and MacProject II has replaced Artemis as the team-level tool.

1. Frameworks

We were told that the framework is the concept that will enable concurrent engineering. The framework is a new software layer that creates a context for the shared information. It provides a way for a person to get needed data, and it can keep track of the design configuration and allow work to proceed on several design versions simultaneously. Frameworks make it possible to do iterations on product design an order of magnitude faster and eliminate time spent dealing with non-value added available information.[18] Frameworks can also facilitate documentation, storing the minutes of all design reviews and meetings.

The purposes of the framework, summarized by IMS, are—

- To provide a repository for product development data.
- To facilitate rapid access to the latest baseline product data.
- To reduce and eventually eliminate redundant product definition data.
- To share product definition data between enterprise engineering and manufacturing tools.
- To enable end users to locate data of interest
- To provide a data structure and human-machine interface encouraging disciplined IPD.
- To manage the sequencing and flow of work among the enterprise functions.

The IMS concept of a framework is shown in Figure IV-2.[19]

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[18] Typical time spent without a framework can be 25 to 30 percent in translation of the data and 35 percent in finding and verifying the data.

[19] There are "Framework" initiatives under both the MANTECH and the Defense Advanced Research Projects Agency (DARPA) Initiative in Concurrent Engineering (DICE) programs. The MANTECH Directorate, Integration Technology Division, at WPAFB has a program called the Enterprise Integration Framework (EIF), and the follow-on is the Enterprise Integration Program (EIP). A Lieutenant Guss heads the Air Force program. Northrop and D. Appleton are also active in frameworks.

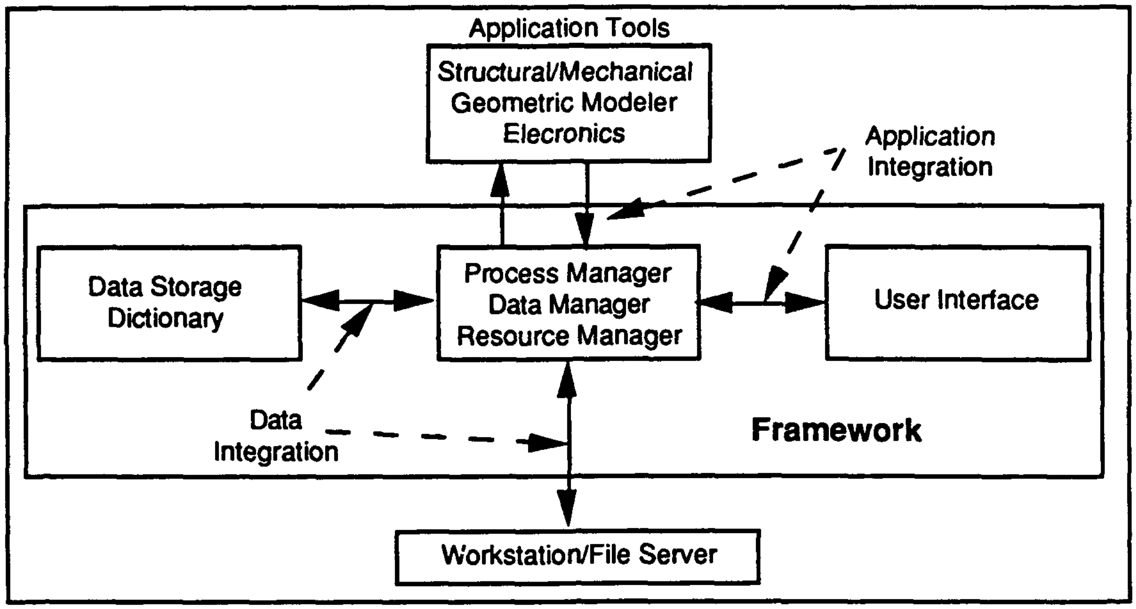

Figure IV-2. GD Convair's Enterprise Framework

An object-oriented data management system layer will reside above other hierarchical and relational data managers as may be appropriate to the large set of applications.[20] Not only must the framework data manager allow easy user access to the product data, but the data must be presented to the user in the appropriate view as follows:

- Assembly View, needed by manufacturing engineers and on the shop floor, including tooling model, numerical control program, manufacturing process.
- System View, needed by the design engineers for the way the work gets organized, including the requirements, analyses, trade studies, design concept, manufacturing concept, tooling concept, numerical control concept, schematics, wireframes, external outline of product, system mockup, component solid models, and parts list.
- Functional View, needed by the customers for the Statement of Work (SOW), including customer requirements, functional flow diagrams, and derived requirements.
- Task View, needed by the program managers for the Work Breakdown Structure (WBS), including schedules, deliverables, work packages, and tasks.

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20 GD Convair uses 300 different application tools.

IMS personnel are working on enterprise framework models which they do not anticipate will be completely developed 1 to 2 years off. They told us about various vendors that have frameworks now on the market. Mentor Graphics has Falcon Framework and the Digital Equipment Corporation (DEC) has Power Frame. Dr. Peter O'Grady at South Carolina is also working on a framework. The question may become how to work in a world with multiple frameworks? DEC is recommending A Tool Integration Standard (ATIS) as the framework standard, and we were told that ATIS is now being presented to the International Standards Organization (ISO) and national standards committees. ATIS has to do with how one invokes a program and gets the data.

2. Standards and Computer Systems

We were told by the IMS personnel that computer technology is not a limitation—in 5 years, it is envisioned that everyone will have a little Cray computer on his or her desk. Instead of technology being a limitation, standards were viewed as being critical, and IMS personnel believe that industry users must agree on them for the aerospace market to grow. Vendor tools should have a common user interface, and industry must get involved with the standards committees to ensure that this happens. GD's essential standards include Unix for the operating system, IEEE POSIX (operating system interface), Xwindows-based OSF/Motif for window management, the Structured Query Language, SQL,[21] Transmission Control Protocol/Internet Protocol (TCP/IP) for networking, and ORACLE as the data integration standard. When considering software for the Convair Division, IMS must consider how it fits into these standards. GD Convair's Computing Architecture and Network (CA&N) project also emphasizes the Product Data Exchange Standard using the International Standard for the Exchange of Product Data (PDES/STEP), which is becoming a de facto national standard,[22] and the International Standards Organization's (ISO's) Open Systems Interconnect Model (OSIM).

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21 Engineers at GD Convair see the OSF/Motif window management standard and SQL as key enabling technologies for concurrent engineering. The object-oriented, distributed data base is also seen as crucial technology for concurrent engineering.

22 PDES/STEP is being developed internationally with the testbed at the National Institute for Standards and Technology (NIST) in Gaithersburg, MD. STEP is a related international standard. PDES will provide a comprehensive product definition format including both mechanical (IGES) and electrical (EFIF) design. It may be a while, however, before it is realized.

Some software tools that GD Convair is using include SINDA for heat transfer analysis; Mentor Graphics electronic CAD (E-CAD), NASTRAN for strength analysis of transient loads; ASTROS for multi-disciplined structural optimization;[23] RAMCAD for reliability, maintainability, and supportability analysis;[24] Euclid for solid modeling and electronic mockup; and Euclid's built-in Qwicksolver for structural analysis using finite element modeling. We were told that Euclid was chosen because of its potential—it has a good open architecture and a true potential for integration. Euclid and Mentor Graphics have shared data bases for multi-users, which encourages good IPD in some limited sense. The Integrated Process Planning System (IPPD) project at GD Convair is implementing and integrating a commercial tool to facilitate the design of the production process in parallel with the design of the product.[25]

D. USE OF TECHNOLOGY

At the CALS/CE Conference & Exposition, Wayne Uejio from GE Corporate Research identified the activities of product development as looking up, computing, communicating, negotiating, deciding, and archiving.[26] He identified the current technologies used for each step as follows:

- Look up—manual dissection of data bases and handbooks.
- Compute—networks of connected heterogeneous computers.
- Communicate—low bandwidth, discrete media (telephone, fax, electronic mail).
- Negotiate—face-to-face meetings.
- Decide—specialized, single-perspective decision-support tools.
- Archive—notes, files, personal memory.

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23 ASTROS was developed by Dr. Venkayya at the Flight Dynamics Laboratory, Wright Patterson AFB.

24 RAMCAD, Reliability, Availability, and Maintainability in Computer-Aided Design, was developed by GD Convair under a joint Air Force-Army program, administered by the Acquisition Logistics R&D Activity.

25 IPPD is based on CIMTelligence Corporation's Group Technology-based Computer-Aided Process Planning System.

26 Wayne H. Uejio, Scott Carmody, and Bruce Ross, "An Electronic Project Notebook for the Electronic Design Notebook (EDN)," *Proceedings of the CALS&CE Washington '91 Conference & Exposition,* Featuring the Third National Symposium on Concurrent Engineering, 10-14 June 1991, pp. 527-535.

He then went on to describe his vision of tomorrow's technologies as follows:

- Multimedia conferencing—"in-situ" meetings via high-speed multimedia networking.
- Instant access to community data bases, knowledge bases.
- "Yellow pages" of computer tools and data resources.
- Transnetwork (transparent) computing.
- Automatic capture of "intellectual enterprise".
- Perspective-centered virtual environments.

This view of the future is behind GE's development of the computer system MONET (Meeting On the NETwork) under the DARPA Initiative in Concurrent Engineering (DICE) program. Although we share this vision of tomorrow's enabling technologies, many issues complicate the implementation of any enabling technology for IPD. These include the heterogeneity of the hardware and software environment, a lack of standards so that the heterogeneous machines can communicate, and the poor user interfaces that keep the new technology from being used easily. Above all, each company has its own legacy systems that are costly to replace. Whatever path the development of tomorrow's technologies takes, customers need to be able to exploit future enabling technologies without excessive cost, unnecessary risk, and disruptions in their operations.

When we visited GD Convair, the engineers there had the same view of tomorrow's environment for product development, but elaborated on the problems associated with technology and how it will affect the concurrent engineering team. They saw the data transfer speed and the capability of the machines to process data and translate—the fast reaction—to be critical in making the team effort work. They suggested that any group support system (GSS) developed for concurrent engineering would have to allow fast iteration and reaction so that the specialist engineer could act as quickly as the designer. One enabler for this is that today, unlike in the past, many applications for engineering design and analysis can be done in real time. However, slow communications and the legacy hardware and systems that industry now has will have to be overcome. For a complex design, the number of workstations is as important as the number of teams.[27]

[27] The ratio of engineers to computers at GD Convair is 7:1 for workstations and 3:1 if high level PCs are included.

Industry has a huge investment in the hardware and systems that are now in place. Upgrading is costly and occurs rather slowly.

Engineers need to communicate graphically, and the computer communications of graphics information can be extremely slow. The GD engineers see their greatest limitation as the inability to just get data back and forth efficiently—they even said that the "sneaker net" is sometimes still the most efficient.[28] The GD engineers said that even with the installation of fiber optics communications (100 megabits per second, MBPS) at their site, they are often limited by the machines themselves.[29] Even for the successful use of SAWS for the Advanced Cruise Missile (ACM), the data importation issue was the biggest problem. The technology focus needs to move to the communication—and specifically graphics communication—area. This is a comment we have heard often.

The GD engineers also talked about problems with translations between different software packages, including SAWS. They said that they needed custom translators to get rid of the redundant data on Euclid. Even if the CAD data is available for specific applications, it may still have to be reentered. They stressed that these data transfer issues were critical and that they must be resolved; they expressed hope that the data exchange standards will help. They said it was very difficult to work with the vendors. GD has had good success in writing custom translators, but these translators need to be based on the vendor's internal software storage techniques, which change with every new release of the software.

Change Management is the term used for transforming human behavior and managing the transformation created by the implementation of new technology. GD Convair engineers told us that the key to a disciplined product development process is to embed the standard, best practices and procedures in a subtle way—to make it easy for the user to do the right thing. There is a great need for computer programs that encourage the use of good practices and eliminate manual checking. The way to get engineers to use a new tool is to put a low burden on them—to make it so that they will no longer have to

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28 The "sneaker net" involves putting the file on a floppy disk and hand-carrying it over to the other machine.

29 The RAMCAD Lessons Learned by GD Convair included an example. The latest fiber optics communications offered by DEC can support 100 megabits per second transmission. However, at a demonstration given at DECWorld '90, the fiber optics system was transferring data between two of DEC's fastest workstations at only 30 megabits per second. The state-of-the-art workstations could process only 30 megabits per second, a much slower rate than is required for real-time transmission between graphics workstations.

reenter the data or do the manual checking. Design rules checking was seen as too often occurring after-the-fact and was deemed to be an appropriate part of the framework. Any framework developed will have to be able to accept the academic expert systems and the design rule checkers currently being developed. The ability to capture lessons learned has to be built into the tool by the vendor and must provide a convenient way to surface the lessons. It can't be added later, and it must be tailorable to be useful. GD Convair engineers are experimenting with HyperKnowledge to be used as a tool for organizing and extrapolating knowledge from a historical design.

Another lesson learned during GD Convair's development of concurrent engineering is that there is no need to integrate a specialty application into the CAD system itself. Dedicated workstations should just be tailored to the specific function or specialty application they are being used for as long as they also have the capability of procuring the right information from the CAD system and the ability to transfer the results of the analyses back to the designer. They said that Crew Chief was part of the CAD package and not on a dedicated workstation, so that it ran too slowly for efficient use by a designer.

E. USE OF HUMAN PERFORMANCE MODELS

GD Convair has developed a human performance model called the Supportability Analysis WorkStation (SAWS). A three-dimensional model of the current design can be transferred from the GD Convair's CAD data base. The SAWS translation needs only surface data, however, and not the full 3-D CAD instruction. SAWS gives speed close to real time and gives the ability to see the entire soft mock-up and assemble all the components. Previously determined by hard mock-up, now SAWS allows a trade between design attributes and support. The GD engineers commented that the LSA process is supposed to design the support system *and* influence the design for supportability. However, the emphasis had always been on the former and only lip service was given to the latter. Now SAWS does give the ability to do the trade-offs necessary for design influence.

GD Convair maintained that SAWS was applicable at various stages throughout the design process.

- Conceptual Design: Simulate how a space system interfaces with the launch tower.
- Preliminary Design.

- Detailed Design: Simulate the use of standard tools, nuts and bolts.
- Operations and Support: Simulate the loading of a missile, the activity of humans at the airport, the effects of exhaust from service vehicle.
- Safety in O&S: Simulate how to operate the system.
- Support Equipment: Simulate how to base, how to load on airplane, inbound logistics of the missile.

When the SAWS program is run, all the data that can be read in automatically is. Without the CAD data available, the geometric model of the equipment must be built first before SAWS can interact with it. The time to do this did not appear to be too much of a limiting factor; the SAWS operators told us they built a sufficient model of a submarine in one day.

We discussed the importance of a model such as SAWS for use in maintenance analysis. The engineers said that organizational maintenance was much more important than depot maintenance. A McDonnell Douglas study found that every minute that turnaround was reduced, the probability of survival goes up. This ability translates into thousands of dollars. Saving time in the depot is not as important as saving time on line, although there may be some point of doing the analysis for depot maintenance issues of accessibility and safety. The physical interface with the systems (accessibility) and collision detection (safety) were seen as both very important.

Using the model to come up with times required to perform a task was not seen as important because the times turn out to be the same as the Time Standards (TSs). TSs are good because there is so much history behind them. GD has used SAWS images in technical orders (TOs), but the technical order people use a different system.

When asked the types of things that would be desired in a human performance model, the GD Convair engineers stressed that speed was the most important factor and that a high level of fidelity was not required. A high degree of detail is required for simulations for the operator, but not for the designer.

Dynamic modeling (kinetics) is important over static modeling with respect to safety issues due to part/tool/equipment failure, e.g., what happens to the person's hand when the bolt breaks? The force of gravity could be added to the model to have the ability to simulate mistakes and accidents, e.g., where does the bolt go when it's dropped?

The algorithms used to find the most efficient path for movement are similar to those for wiring diagrams. One technological advance would be to take the algorithms out and use virtual reality to try and do the tasks. For example, the analyst could put on a virtual reality glove to analyze the design for the repair/user interface.

The engineers at GD Convair said that the Service data is operator-oriented—for healthy, young enlistees—and it doesn't reflect the maintenance crew either on the flight line or at the depot. Other comments about the data were that—

- Vision data is currently available to support the model in terms of cones of vision, peripheral vision, looking at two different things at once.
- Hearing data for auditory questions could be useful, but not for flight-line maintenance—the technicians can't hear anything in that situation anyway.
- The ability to calculate stress on technicians would have a high pay off on the flight line. Currently GD does have Monte Carlo task simulations to calculate the Mean Time To Repair (MTTR) under various stress conditions.
- Cognitive modeling could be useful for diagnosing a fault. If the analyst has the ability to know how difficult the diagnostic tasks are, he or she could notify the designer if the design were getting too complicated and could, say, be serviced only by the top 5 percent of technicians.

The engineers also noted the utility of HCT for training or for indicating a need for more training. They said that people are not well trained on what has to go where and that HCT could be useful because of the lag time between hard mock-ups available to train on. It would also be helpful if HCT could be used to somehow trace or put together the fault tree. Lessons learned data was also brought up and the desire to incorporate it into the CAD system to flag the designer and act as a design advisor.

V. LOGISTICS CENTERS

As indicated in Chapter II, Section B.2, the Air Force Logistics Command (AFLC) identified its core functions as Requirements, Acquisition, Distribution, and Maintenance. The focus of this chapter is the Air Logistics Centers (ALCs), where much of this maintenance function takes place. Maintenance of AF weapon systems involves the greatest percentage of the AFLC work force. Nearly 39,000 maintenance people work in the field organizations. Responsibilities of the maintenance function range from advanced technology in support of new weapon systems to modification, overhaul, and repair of older systems for which parts are often not reliable or even available. With assistance from the aerospace industry, the maintenance organizations provide in-depth repair and modernization of about 1,270 aircraft, over 6,000 engines and engine modules, and 800,000 parts for these systems annually.[1]

The military uses three levels of maintenance: organizational, intermediate, and depot.[2] Although organizational- and intermediate-level maintenance can be performed in the field or at a base, depot is the appropriate level of maintenance for overhauls and upgrades to be performed. In the Air Force, depot maintenance typically occurs at the ALCs. This chapter discusses the ALCs in general and the Oklahoma City ALC (OC-ALC) in particular. Currently there are five ALCs, which are shown in Table V-1 with the systems for which they are responsible.

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1 *Application for the President's Award for Quality and Productivity Improvement 1991*, Air Force Logistics Command.

2 The Air Force has recently gone to two levels of maintenance.

Table V-1. ALCs and Associated Systems

Air Logistics Center	Specialty Systems
Ogden ALC, Hill Air Force Base, UT	F-4, F-16 aircraft
Oklahoma City ALC, Tinker Air Force Base, OK	B-1, B-2, KC-135, B-52, missiles, and the F-101 (B-1), F-110 (F-16), F-118 (B-2), and F-108 (KC-135) General Electric engines
Sacramento ALC, McClellen Air Force Base, CA	A-10, A-7, F-111, F-117, space and C3 equipment
San Antonio ALC, Kelly Air Force Base, TX	C-5, F-6 aircraft; T-37, T-38 Pratt & Whitney engines
Warner-Robins ALC, Robins Air Force Base, GA	F-15, C-130, C-141, helicopters, missiles, common avionic equipment, electronic warfare equipment

An ALC receives its resources through work load projections and contracts with the Air Force Major Commands, which budget for the ALCs. Non-Budget funds come from work done for the Navy, the Air National Guard, and the Air Reserve. These are Reimbursable Funds customers, who "pay as they go." Until recently only a very small percentage of the funds came from them, but under the new DoD regulations that require competition among the Service's depots and industry for repair and overhaul of weapon systems, there is a feeling that the percentage may change.[3]

The following sections describe some of the activities in the Depot Maintenance processes. Many of the processes require team meetings and are closely linked to the QP4 (TQM) processes of the AFLC (e.g., preproduction planning, depot activation). It will be seen in this chapter that the design of the depot maintenance/repair/overhaul process is on a scale comparable to the design of a product. The same types of iterative processes occur, from requirements generation through final design. Just as Human Centered Technology (HCT) could be used in product design, it could be used in process design at ALCs. The many processes that require interaction and decision making by a team or wide group of people are target opportunities for Group Support Technology (GST).

3 See Section A.1, below.

A. PROCESSES WITHIN THE ALC

This section describes the processes that affect and occur at the ALCs. Much of this information was derived from Air Force Regulations, so it applies to all of the ALCs and all organizational structures. Specific functions in the current organizational structure are defined in Section B and are based on our visit to OC-ALC. These processes are intensely group-oriented, requiring group decisions on a wide basis. Throughout these processes are various opportunities for applications of GST and HCT.

1. Choosing a Repair Facility

Currently, the ALC for a new system is specified in the Program Action Document (PAD).[4] HQ AFLC does a Decision Tree Analysis (DTA) to determine whether it is more economical to repair a new weapon system at a depot (called "going organic") or at a contractor facility. Decision criteria include surge, work load, facilities, availability, and expertise. In some cases the system could even be fielded before it goes organic; in other cases the depot could be activated on an engine before it's ever in the field. In general, the AFLC rule of thumb is that the system must be organically capable when "the rubber meets the ramp." The responsibility for the weapon system transfers from the Systems Program Office (SPO) (the focus of Chapter III) to the System Program Managers (SPMs) at the Air Logistics Centers in the Program Management Responsibility Transfer Document (PMRTD).[5]

In the past, depot maintenance work load assignments were generally made in one of two ways, depending upon the nature of the work. When a major end item or system was involved, HQ AFLC determined which Center would receive the new work load by considering the types of skills, facilities, and support equipment that were available to perform the work and by assessing which Center was most capable of accepting the work during the period of its anticipated existence.[6] The chosen Center for a major weapon system was submitted to the SPO and accepted or rejected by the SPO. For items other than major end items or systems, the assignment of work to the Centers was pre-

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4 This is also the document that describes the SPO activities.

5 Soon to be overcome by the implementation of IWSM.

6 When an ALC is chosen, it is generally chosen according to its traditional line of expertise (engines, airframes, missiles, electronics). For example, OC-ALC traditionally has the responsibility for General Electric (GE) engines and San Antonio ALC takes care of the Pratt and Whitney (P&W) engines. In theory, however, any Propulsion Directorate could be assigned any engine, depending on its work load.

established through the Technical Repair Center (TRC) concept. Proper assignment meant selection of the most appropriate technology needed to support each new end item. The responsible Directorate submitted information to HQ AFLC on the repair process, support equipment (SE) requirements, work load and skill levels, and the recommended TRC assignment. This plan was either accepted or rejected at HQ AFLC.[7]

For the future there is a requirement, resulting from the Defense Management Review (DMR), for the repair and overhaul business to become competitive. Although the ALCs already repair and overhaul systems from the other Services as well as the Air Force, the business will become even more inter-Service in the future. Bid packages will be required for new business. The ALCs are still learning how to prepare these packages.[8] The ALCs will be competing against contractors, other defense organizations, and other ALCs.

2. Depot Activation[9]

Depot activation refers to the capability of a repair facility to begin production levels of overhaul when the appropriate level of maintenance is the Depot. This appears to be an intensive group process that could benefit from GST. Many working groups are formed to accomplish the formidable task of selecting, procuring, funding, and activating a new system for the Air Force. The principal group is the Logistics Steering Group (LSG), which is chaired, along with most of the other groups, by personnel from the HQ of the Aeronautical Systems Division (ASD).[10] The purpose of the LSG is to oversee and review logistics concerns and issues. The purpose of the next group in importance, the Integrated Logistics Support Working Group (ILSWG), is to identify and solve problems relating to the system. The ILSWG is composed of representatives from all the affected activities, including the end users.

The third prominent group is the Depot Maintenance Activation Working Group (DMAWG), whose purpose is to identify and solve problems relating to maintenance overhaul such as support equipment (SE), training, technical orders (TOs), and supply

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7 AFLC Regulation 66-4.

8 The ALCs do not have the marketing expertise that a contractor has, so there was some feeling at OC-ALC that the contractor will have the advantage in the bidding process.

9 This section is derived from a paper written by Dave Laukat, Production Planning, OC-ALC, which describes the Depot Activation for GE's F-110 engine.

10 Called the Aeronautical Systems Center in the plan for AFMC.

items. Group members come from ALC depot maintenance functions, ASD, the prime contractor, and any other logistics or engineering support areas. Other groups are formed as needed to solve specific problems and are then dissolved.

3. Maintenance/Production Process Planning

Once the TRC is chosen, the Source of Repair (SOR) is chosen. The SOR and the TRC are usually the same, but they could be different. These choices are made during the system development at the same time the contractor—in concurrence with the SPO and the ALC—develops the Technical Orders (TOs) and the support equipment (SE) requirements.

The System Manager or Item Manager (SM/IM) in the Management Division chairs a work specification review with the TRC subsequent to the preparation of the Maintenance Work Specification. This review is comparable in detail to a Contract Program Pre-award Bidders Conference. The Item Management Specialist must process a Management of Items Subject to Repair (MISTR) Negotiated Repair Requirement for all items projecting a first time repair requirement. One of the ALC automated data processing (ADP) systems then produces the MISTR process requirements. This process begins with the Item Manager projecting repair requirements and the equipment specialist verifying with the maintenance planner that support equipment and technical data are available. A Temporary Work Request is issued for validation and verification of SE and TOs for a serviceable unit and first article prototype and for establishment of labor and material standards.

The Technical Requirements Control Point (TRCP) in the Production Engineering Branch at the ALC then ensures correct processing and control of the Maintenance Work Specification. The TRCP is responsible for reviewing, controlling, and distributing the work specifications, including the Time Critical Technical Orders (TCTOs), to the proper Sections in Production Engineering. The organization responsible for the work then responds to the TRCP, either confirming or denying capability. The production management specialist then issues a MISTR Fiscal Year Repair Requirement for determining repair work load and parts' supportability. The supply specialist reviews the supportability document for the Defense Logistics Agency (DLA) items and expedites shortages. The supply specialist issues a report to the production management specialist on the parts' status prior to work load negotiation. The work loader negotiates the work load for the maintenance activities and ensures sufficient funds and leadtime to accomplish the repairs. The production engineer plans the work load, develops the Work Control Documents (WCD), and determines tooling, facilities, consumables, expendables, and

training. The WCD gives the authority to do the work and has to be coordinated with Scheduling and Production. A planning meeting is conducted at which tasks are assigned to support branches (to determine constraints and tooling) and consumables and expendables are ordered. The planning folder is released to Resources Standards once the WCD history file is updated, including any material and labor change requests. The industrial engineer establishes the labor and material standards and the sales price. The scheduler inputs the work load, notifies of material requirements, and notifies the shop of a firm schedule. Lastly, production performs repairs and notifies the scheduler of work completed.

Currently, work requests and Temporary Job requests can be produced electronically using the ADP systems. The process is automated until the Technical Repair Control Point, where the digital information is converted to paper; that is, the process is electronic only up until labor and materials. The goal of the Depot Maintenance Management Information System (DMMIS), described in Chapter III, is to automate the whole process.

a. Prototype/Technical Order Verification

During Prototype/TO verification, the contractor-validated TOs and SE are verified for accuracy and compliance. Repair development validation is the process by which the contractor validates that the repair process will work. Verification is done by the Air Force to prove that the repair procedure will work in an ALC facility. Ideally, the contractor validates SE and TOs before the Air Force begins its verification effort so that many hours are not wasted in modifying SE and rewriting technical data.[11]

Prototype Verification is used to determine the maintenance characteristics and support requirements of an end item by having skilled personnel in the actual depot maintenance environment perform the tasks prescribed in the work specifications. This process provides information about the repair of an end item that has not been otherwise obtainable. It helps define the customer's requirements; establish optimum maintenance methods, techniques, and procedures; verify, refine, or establish labor and material requirements; verify tech data, SE, and safety; and evaluate the adequacy of planned

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11 Stephen Jaworsky, *Potential Lessons Learned Submittal Record*, MAENA, 14 September 1990. (Hereinafter referred to as *Potential Lessons Learned.*)

support equipment and shop layout to determine necessary refinements.[12] Prototype Engine Verification at the OC-ALC for new or modified systems is not done with computer simulation but by actual performance demonstration, e.g., time and motion studies, safety analyses for existing systems.

The timing of Prototype Verification varies. Sometimes it is done late in the development process, when many units are already fielded; sometimes it is done early (e.g., the F-118 engine for the B-2 Stealth bomber). The design needs to be pretty well established—at least a baseline design, say at the Preliminary Design Review (PDR) or the Critical Design Review (CDR). HCT in the form of simulating the human interaction with the CAD model could help in earlier verifications and eliminate the need for a hard mock-up.

The rejected systems go back to the contractor for redesign when they don't pass the Prototype Verification—especially for safety reasons. This is an iterative process: disassemble by current tech order, test, and build up again; rewrite tech orders, cowrite support equipment and process descriptions; modify design.[13] As with concurrent engineering the ability to cut the number of iterations and do it right the first time saves money. HCT that could help reduce the number of iterations should lead to fairly quick rewards for management.

b. Preproduction Planning

Pre-production planning occurs after the TRC assignment but before the new weapon system becomes operational (or at least concurrently with the operation phase). For each new end item, pre-production planning teams composed of representatives from the scheduling, inventory control, quality assurance, and engineering/planning functions as well as shop personnel must be established. This team process is closely linked with the QP4 (TQM) efforts of the AFLC. The team is chaired by the lead Engineering/Planning technician and may include members from other functional groups as needed on a part- or full-time basis. When TRC work load assignments are transferred, some preproduction planning is required by the receiving TRC.

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[12] AFLC Regulation 66-4.

[13] Concurrent engineering between the contractor and the ALC personnel could help alleviate this series of iterations.

Pre-production planning can also occur on an ongoing basis for major end item repair requirements that generate after the initial TRC requirement and for major modifications, such as those required for safety of flight life support or generated by activities of the depot field team (DFT).

c. Production Planning

Production planning is started upon receipt of the work load authorization document. Labor standards and material standards are developed during this process. Figure V-1 illustrates the production planning process and some of the required documentation.

d. Local Manufacture

During manufacture, raw material is transformed into an item with a specific fit, form, and function. The Management organization has the basic responsibility for determining whether manufacture at the ALC is authorized based on the following criteria:

- Organic manufacture is necessary for the Air Force to maintain an in-Service depot maintenance capability for mission-essential items.
- Acquiring the part commercially will result in a higher cost.
- The product isn't available from any other Service or Federal agency.
- Acquisition from private commercial sources will disrupt or materially delay an Air Force program.
- A satisfactory commercial part is not available and cannot be developed in time to provide the part when needed.

Proposals can also be made for the local manufacture of depot maintenance shop equipment through the engineering/planning organization.

e. Component Improvement Program

The repair process for a new engine is first defined in the repair manual[14] by the engine contractor. The "lead the fleet" systems are used to identify problems and generate repair requirements. The Component Improvement Program (CIP) is used in an effort to

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[14] Some people at OC-ALC said that they do not find this document very useful (see Section B.1.a).

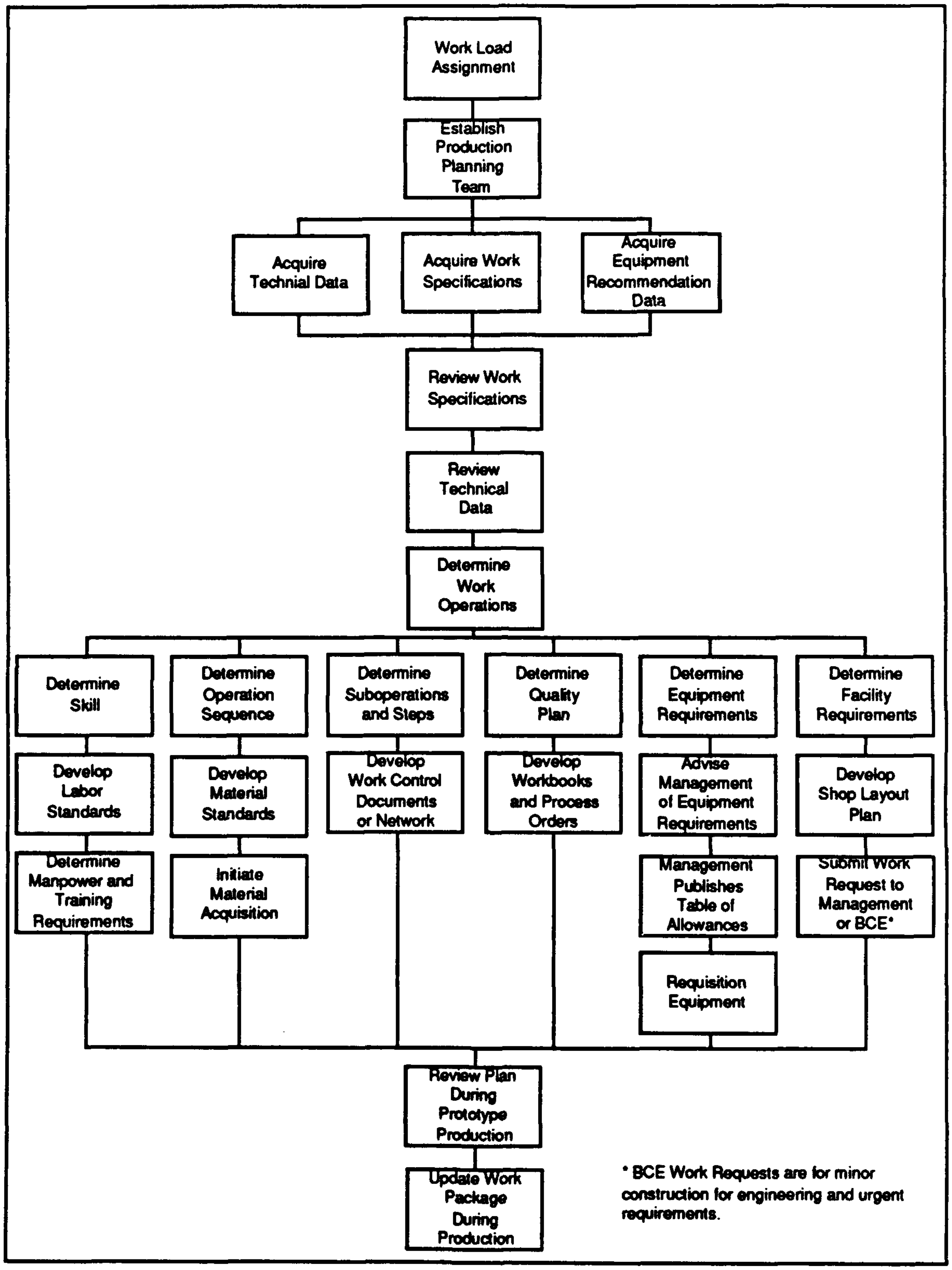

Figure V-1. Production Planning Process

anticipate what will break and is always initiated for a safety-related problem. New repair requirements come mostly from the CIP program and are verified via prototype. The ALC engineers are the CIP monitors, but the CIP program authority rests with the SPOs.

For example, the F101-GE-102, F108-GE-100, and F110-GE-100 engines were depot-activated by OC-ALC without common practice repair data in the TO. These common practice type repairs were identified as CIP candidates and formalized in the Technical Data after the Prototype/ TO verification efforts and Depot Activations.[15]

f. Redesign and Modifications

Even after a system becomes operational, it can undergo modifications[16] reflecting reliability, safety, and parts supply problems. A proposal for a modification can basically come from anywhere, e.g., from the field (bases) or the Air Force suggestion program. A contractor can also identify a problem and submit an unsolicited proposal to repair the problem. Requirements for a modification can be identified in the following:

- MDR, Material Deficiency Report.
- WDR, Warranty Deficiency Report.
- QDR, Quality Deficiency Report.
- AFTO 22s - Tech Order Deficiency Identification.

The Material Deficiency Report/Quality Deficiency Report System is specified in technical instructions available to all customer organizations. This formal system, supplemented with contact over the telephone, allows the customer to report specific deficiencies. The failed item is often returned to the ALC to facilitate investigation. Material deficiencies reflect possible design or material problems that may require correction by the ALC technical and engineering specialists. In some cases, the original manufacturer's engineers are required to research and correct serious deficiencies requiring very specialized capabilities.

In-house ALC engineers may do small changes without the contractors, depending on the magnitude of the changes and the availability of funds. An ALC is allowed to make modifications only when they do not affect fit, form, or function. Changes that will affect fit, form, or function have to go back to the contractor to be performed. If funds are not

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[15] Stephen Jaworsky, *Potential Lessons Learned.*

[16] The term *modernization* instead of *modification* seems to be appearing more and more often in the new austere environment.

sufficient to send an item or system back to the contractors, the ALC engineers may have to fix the problems in-house. With the ever-decreasing funds, this situation may occur more and more. As a rule, ALC engineers will try first to do the design and analysis; if they cannot do it, the contractor will do it.[17] Currently the prime contractor does all significant redesign.

B. ORGANIZATIONAL DESIGN OF THE ALC

Over the past year, the ALCs underwent a reorganization along product lines. This type of reorganization is similar to the changes being made in many companies where organization along product lines is perceived to enable concurrent engineering far better than organization by functional divisions.[18] Previous functional divisions at the ALCs that did the actual overhaul/repair processes consisted of Materiel Management (MM) and Maintenance (MA). In general, Management included the engineers and managers (white collar) and Maintenance included the people who worked on the shop floor (blue collar). The product directorates at the ALCs now include Aircraft (LA), Propulsion (LP), and Commodities (LI). Not all ALCs have all three products, and some ALCs have additional special product directorates (for example, Sacramento ALC has a Space and C^3 Directorate and no Propulsion Directorate). Each of these product directorates contains Management, Production, Resources Management, and Contracting Divisions. All of the ALCs also have a Technology and Industrial Support Directorate (TI), a Contracting Directorate (PM), and a Communications and Computer Systems Group (SC). These organizations align with the formation of the AFMC discussed in Chapter II.

The OC-ALC has both an Aircraft and a Propulsion Directorate. We visited with personnel from the Propulsion Directorate, which consists of four divisions:

- Propulsion Management (LPA).
- Product (LPP).
- Resources Management (LPM).
- Propulsion Contracting (LPD)

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17 OC-ALC gave a counter-example to this standard process: the contractor came up with a new design to fix an oil leak that just made the engines more susceptible to oil leaks. The ALC engineers ended up fixing the problem in-house.

18 The jury is still out on which type of organizational design is best for concurrent engineering. Our research indicates that it is dependent on such factors as the complexity of the product being developed, the legacy or history of the organization, and the number of technical experts (as opposed to inexperienced people) available in each function.

Figure V-2 illustrates the branches within the Product Division and the sections within the Production Branch and Engineering and Planning Branch (these are the sections on which we have acquired the most information). The Resources Management Division is responsible for the overall maintenance work load planning for requirements, repair sources, manpower allocation/authorization, manhour capability, and alignment to AFLC work load plans and working shifts.

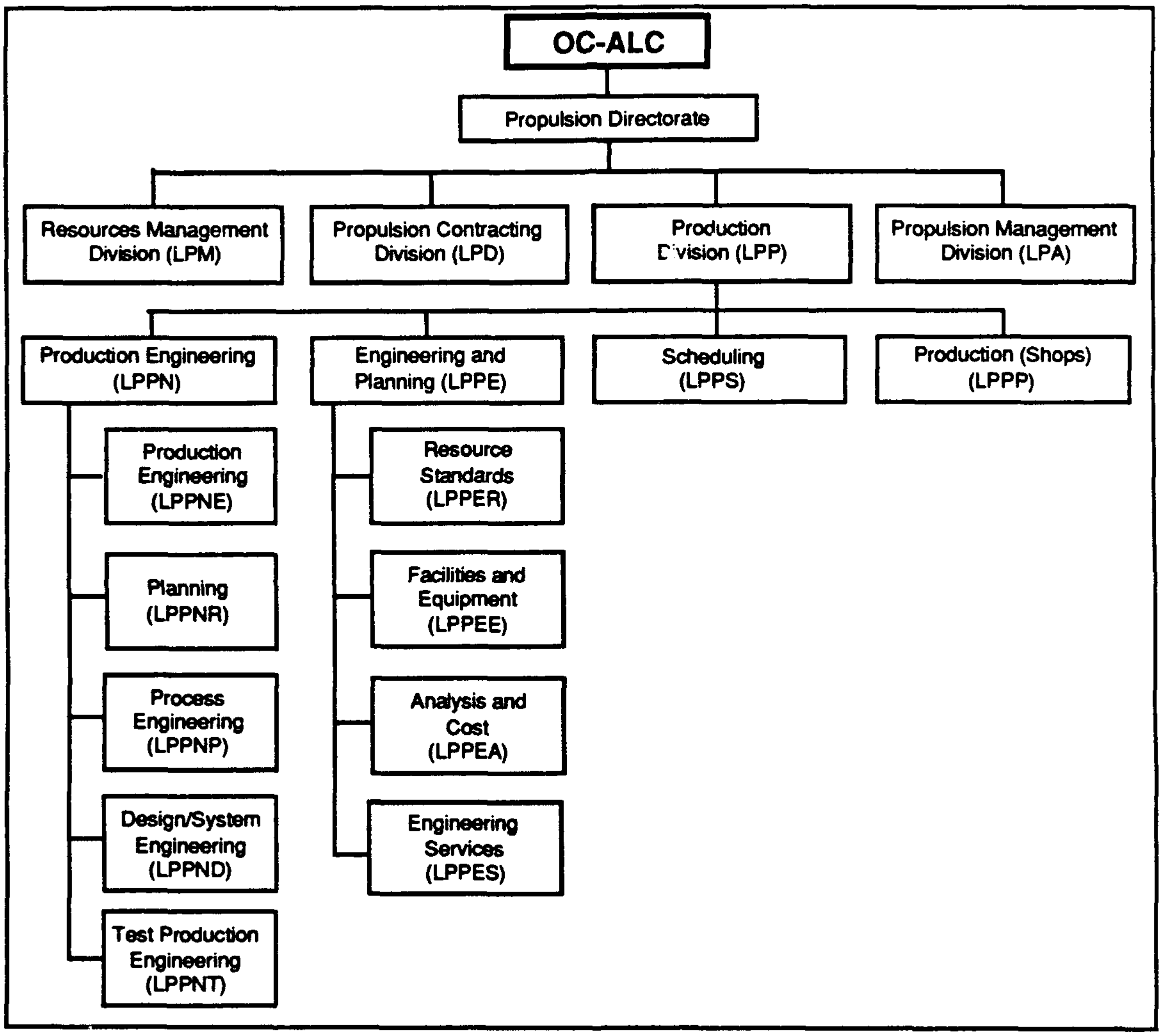

Figure V-2. OC-ALC Propulsion Directorate (Incomplete)

The Propulsion Directorate at OC-ALC consists of 19 military and 2,370 civilian personnel. OC-ALC does depot maintenance on engines from Pratt and Whitney (P&W) and General Electric (GE) and Allison, Rolls, Garrett, and Williams (missiles). The number of engines that the Propulsion Directorate overhauls and repairs in a year is highly variable, and the number of new systems and modifications also occurs in cycles. For

example, the GE F101-102 engine that powers the B1-B aircraft was the first new engine to be planned at the OC-ALC since the TF41 engine in the mid-1960s. Arriving at a specific number of engines repaired and overhauled is a complex process—at any one time OC-ALC could be working on modifications of pieces of engines as well as overhauling complete engines.

Although a portion of the engine repair is contracted out, the airframe in-depth overhaul is primarily done at the ALC. Although phase inspection on the engines can be done when they are still on the airframes, the engines are generally brought in separately from the airframes because depot maintenance funds cannot be spent on intermediate level repairs.

During our site visit to OC-ALC/LP, we met with acquisition engineers and technical services people from the Propulsion Management Division and with people from three Branches (Production Engineering, Engineering and Planning, and Scheduling) of the Product Division.

1. Propulsion Management Division

The Propulsion Management Division (LPA) has 350 people, 100 of whom are in Technical Services. This division does the functions previously done by Material Management (MM) before the reorganization of the ALCs. LPA is responsible for the technical information and its configuration control for all engines assigned to the OC-ALC anywhere in the world. LPA has to work closely with the contractors in industry during both pre-production and production and with the Product Division during overhaul and repair.

The branches in this division include Acquisition (LPAA), Engineering (LPAR), Strategic (LPAJ), Tactical (LPAT), and Software (LPAS). We talked with representatives of all of these branches on our visit to OC-ALC.

a. Acquisition Engineering

The acquisition engineers develop repair procedures after an engine's design is finalized. Although this process is well-defined, we were told that the predictive accuracy for repair requirements is poor, and needed information is not obtained quickly. The problem is the difficulty in determining in advance just which parts will go bad until they do so in the field (e.g., the F-16 is just now generating a large number of repairs).

Acquisition engineers discover these problems and discuss their repair concepts with several offices at the ALC and with the contractor. They perform analytical condition inspections (ACI) to detect wear problems and help evaluate failures as part of the investigative team consisting of ASD, the contractor manufacturer, the Safety Office, the SPOs, and the Air Force Accident Board. Failure evaluation is a travel intensive process, which is becoming more difficult to achieve due to the lack of funds.

Repair development validation, in which the contractor validates that the repair process will work, is witnessed by the acquisition engineers. Acquisition engineers also perform the Component Improvement Program (CIP) processes on new engines and develop the required Engineering Project Descriptions (EPDs) that define the work to be done. When the repair EPD is contracted out, acquisition engineers must participate in quarterly meetings on the status of the new work. Acquisition engineers also conduct daily conversations (phone or fax) with the contractor and visit with the contractor's local representatives.

Acquisition Engineers participate in the non-conforming material reviews (NCMR) for non-specification parts uncovered by procedures. They decide on the part's disposition—fix, dump, or use—and define critical information regarding the part performance. The part could be put in a warehouse until it could be repaired, it might be beyond repair, or it may require non-standard repair. If an item can't be repaired in-house, a repair contract is made with an outside contractor. The acquisition engineers work with the contractor during the lengthy approval process for the repairs.

Acquisition engineers address procurement questions on deviations and waivers and act as consultants to the contracting officer on technical blueprint clarifications. They evaluate suggestions and feedback from the system (e.g., line slippage, shortages), contractor deviations from the design or tech specification, and changes to the TO. Acquisition engineers have to deal with shortages, which cause in-house deviations from the TO, and solve other problems that prevent the ALC from meeting its production goals. Much of this work requires group interaction in a distributed environment and may benefit from GST.

b. Technical Services

There are about 100 people in Technical Services (TS) for Propulsion Management who are responsible for maintaining the technical data base. They have the ultimate responsibility for documenting the current configuration of the engine.

Technical Services people work with the acquisition people to monitor reliability by doing failure analysis and safety analysis investigations on site. They develop, maintain, and apply the reliability data as a part of the Reliability and Maintainability Information System (REMIS). They identify and note the trends of failures (wear, heat distress)—especially of the expensive items—and then tell Acquisition which parts to buy. It is a daily effort to monitor the trend, find the problem, and suggest a solution. For example, the B-2 engine already has 71 modifications plus 3 TCTOs.

TS is an initiator of requirements for suppliers and maintainers. TS monitors incoming data, identifies real problems, and suggests actions for modifications or redesign. TS personnel use their experience and "sixth sense" to do this; they have no automation or simulation tools to assist in this activity. They may see a red flag based on monitoring the data and proceed to initiate redesign of an engine because of a reliability analysis. TS personnel determine what design changes need to be made by physically examining and testing the engine, talking to people, or examining data. They then work with the engineers and the contractor to make a modification. Modification is a team effort with the engineers—TS identifies a problem, and the engineers design, test, and develop new parts. TS personnel oversee mods to predict problems.

TS may not approve a new item unless it is cost effective, so TS people may do an economic analysis with the comptrollers. TS can evaluate new proposals by the contractor when the contractor proposes new designs. TS also works with the maintenance shops (field, base, and depot level) on problems to see that the repairs are easy to perform. TS personnel function as technical consultants on the clarity of TOs. They must ensure that the TOs are consistent with the new configuration and that maintenance and parts are properly integrated.

2. Product Division

The Product Division (LPP) accomplishes production engineering and planning functions and acts as the old MA function. This Division must work closely with Management and Plans and Programs. Within the Product Division, there are process

engineers, who are in charge of the engine overhauls, and planning engineers, who plan all the production activities at the ALC.

a. Production Engineering Branch

Production Engineering has total Technical Repair Center (TRC) responsibility for power plant overhaul/maintenance operations. The Production Engineering Branch (LPPN) functions as a direct intermediary between the production overhaul shops and the Management Division. LPPN accomplishes a full range of engineering and technical integration of facilities, tooling, fixtures, and equipment.

LPPN workers provide technical services to the production shops in the form of TO verification, engineering involvement in the shops, and immediate response to technical problems. They are responsible for technology insertion and improving the needs analysis. When a new engine acquisition is introduced, LPPN personnel provide technical data and the SE prototype and perform depot activation and repair development validation. Production Engineering provides all information required for the production planning—work specifications, technical data, and SE recommendations.

Production Engineering has the responsibility to implement all plans and programs initiated by higher headquarters and other organizations relating to depot-level maintenance.[19] This includes analyzing technical data and TOs, blueprints, specifications, and work requirements to establish a systematic work process to repair individual parts, assemblies, and components. TOs and other data are reviewed to determine what needs to be done to the part so that the appropriate repair process can be chosen. These processes include, among other methods, disassembly, cleaning, inspection, welding, heat-treatment, machining, balancing, and assembly. The production engineer determines that the process will not affect the fit, form, or function, or if it does, recommends required engineering changes.

The flow and sequence of the work processes are established down to each step. Where standard repair processes will not suffice, existing facilities and equipment are examined to determine whether they can be modified to perform the necessary tasks. The

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[19] Normal practice dictates that all equipment requirements be established by a joint effort between the engine manufacturer and the Air Force Program Manager's equipment specialist. On the F-110, however, "it was felt by all responsible groups that the OC-ALC Production Engineering Branch could identify more completely and accurately all equipment necessary to overhaul these engines with the exception of unique tools" (David Laukat).

production engineer then recommends to the engineering staff the required changes in equipment or facilities, furnishing all performance specifications. Specialized tools, materials, and equipment are also selected and their specifications prepared.

The production engineer chairs the prototype, pre-production, or problem-solving meetings composed of representatives from scheduling, quality, quality engineering, technical services, engineering, and the production shops to determine and establish production capabilities—equipment requirements, shop layout, flow sequence, and manpower skills and quantities to repair a part, assembly, or component. Production Engineering personnel also attend all meetings of the activation working groups and special problem groups. Bi-weekly production planning meetings are held with all pertinent representatives from the maintenance shops and the contractors to update information and solve specific depot activation problems.

The Technical Requirements Control Point (TRCP), located in this Branch, ensures correct processing and control of the Maintenance Work Specification. Five Sections are located in this branch as follows: Planning, Process, Production, Design/System Engineering, and Test. Minor repairs are developed by Planning; major repairs go to Process Engineering.

Planning Section. The Planning Section (LPPNR) is responsible for planning the overall flow of the engine components through the disassembly, repair, and assembly processes. They develop the work control documents, support repair development, and implement the repair processes and procedures. LPPNR personnel formulate the overhaul scheme for all components, incorporate new requirements, and provide innovative repair fixes. Planning decides what is needed to accomplish the job (e.g., people, materials, tools shop capacity). They determine the workflow, procedures, and provide a step-by-step account of shop work. OC-ALC personnel said that workflow planning can be very involved and that there aren't enough people to actively develop new procedures. Since workflow planning involves the human-machine interfaces of the repair/overhaul equipment, the personnel we talked with in this section expressed an interest in HCT. They said that the size of their staff was small compared with the enormity of the tasks required. Technology that could help them do their work more efficiently would help them a great deal.

The Planning Section works with the Engineering and Planning Branch and the Scheduling Branch to determine the shop capability and with the Acquisition engineers and

Scheduling to determine the supportability of consumables and expendables in the MISTR process. Both the Production Engineering and Planning Sections provide support to the Material Review Board by determining material deficiencies, requirements for additional repair processing, and the need for repair development and improvement. They also condemn components.

Production Engineering Section. The Production Engineering Section (LPPNE) has the engineering responsibility for the overall flow of engine components through disassembly, repair, and assembly processes; it coordinates the repair of components. LPPNE personnel provide engineering support to the disassembly and assembly functions, provide direct support for the production shops, and interact with the Management Division. They provide support to the Material Review Board (MRB), determining material deficiencies and requirements.

Process Engineering Section. The Process Engineering Section (LPPNP) provides metallurgical, chemical, and electro-mechanical engineering expertise to specific overhaul processes and incorporates state-of-the-art technological advances into the overhaul facility. The purpose of LPPNP is to place an engineer in the production environment, so that repair development occurs in a production environment rather than under laboratory conditions. The primary responsibility of LPPNP personnel is to support the production repair shops, maintaining a one-to-one relationship with production personnel and acquiring an overall understanding of production needs and requirements. Process Engineering is supported by a metallurgical group (5 people), a mechanical group (4 people), and a chemical group (4 people); it is supported by complete metallurgical and chemical testing and evaluations in their repair development.

Process Engineering enhances and improves part quality and extends part life by resolving process problems on site, correcting process deficiencies, and improving the processes and procedures (e.g., replacing hazardous materials). LPPNP engineers provide overall total process control of the industrial repair process, developing new improved process procedures and inserting new repair technologies (PRAM, RAMTIP, REPTECH).[20] They provide proper, safe, flexible, and production-oriented equipment to perform the repair function. They control the materials (e.g., chemicals, machine tools, welding wire, plasma spray powders) by writing specifications and developing inspection

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20 Air Force programs for technology transfer, transition, and insertion.

and test procedures for new materials. The engineers also develop detailed process operating instructions in the form of process orders and process operation sheets. They develop and provide process control procedures in the form of test and sample coupons and inspection and measurement standards and provide for the incorporation of Statistical Process Control (SPC) methods and procedures into the processes.

Process Orders can pertain to such varied processes as Certification of Welding Operators, Application of Specialty Lubricants, and Plating of Gas Turbine Engine and Aircraft Components. Process orders stress safety in the procedures and contain the warnings and caution notes for all hazardous operations. The Process Order specifies the using organization and the responsibilities of the various organizations. For example, for Plating, the Plating Shop is the using organization; Management is responsible for specifying the type of plating; Process Engineering is the authority on the correct plating procedures; the line supervisor is responsible for noting all authorized changes in the Process Order; and a team of Process Engineering Section personnel, Production Engineering pre-planners, machine shop personnel, and others as required is responsible for identifying and solving problems related to plating operations or procedures.

Process Engineering provides process expertise to the Material Review Board (MRB) and serves as technical authority for bioenvironmental health and safety. One of its members chairs the Process Review Board, which also includes the Management Division representatives and the production supervisor.

Although the repair process is different for different engines, many of the processes are the same for *parts* of different engines. Repair processes are changed by experience and by experimenting with the techniques. A new process is generally developed over time. It is an iterative development of planning, based on theory or previous experience (build prototype process), testing, tweaking, retesting, tweaking, etc. Safety considerations are primary drivers in the design of a process, and, in the case of new methods, the Process Office decides on the process, equipment, and materials. The development of repairs has to be approved by Propulsion Management (LPA) and the engine manufacturer whenever fit, form, or function are affected. Some processes like the traditional plating processes are well established (prep, plate, deprep). Currently the whole plating shop at OC-ALC is manual because of tradition, the unique requirements of each part, and the low volume. A problem with changing a process is that, for example, "platers are artists"—they don't follow the Process Order.

The OC-ALC uses some CAD for the development of new processes. Interviewees told us, however, that although expert systems may eventually be helpful, the "artists" won't use them because of pride in their work and lack of sufficient detail in the "expert" systems. Research and development is required for a new process, so the Process Office may work with the contractor or use MANTECH or REPTECH program support.

Design/System Engineering Section. The Design/System Engineering Section (LPPND) designs the tooling and fixturing to support repairs. LPPND personnel redesign existing or design new test and production equipment (jigs, fixtures, equipment) for industrial processes. At the OC-ALC, personnel in this Section use some CAD to develop the most efficient and productive design. They maintain and update the official drawings for all of the production's tooling and fixtures. They provide programming support for Computer Numerically Controlled (CNC) machines and the automated and robotic equipment. They write and maintain the programs for the production equipment using trained production personnel with engineering support, and have the capability to download programs to the CNC machines.

Test Production Engineering Section. The Test Production Engineering Section (LPPNT) performs analysis of performance, directs the TRC diagnostic bank, and advises cognizant production engineers.

b. Engineering and Planning Branch

The Engineering and Planning Branch (LPPE) is responsible for Production Planning, which entails the systematic application of engineering and production techniques to determine the processing techniques, manpower, equipment, tools, facilities, and materials to economically produce the required product or services within specified quality limits and a given period of time.[21] The engineering/planning goal is to make the best use of available production resources (manpower, materials, facilities, and equipment) while producing quality work on time. LPPE consists of industrial engineers. Its goal is met by applying industrial engineering techniques in the areas of production planning, facility and equipment planning, and the development of management systems and procedures.

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21 AFLC Regulation 66-4.

The responsibilities of the LPPE are very closely related to Management's Item Manager and System Manager responsibilities. Personnel in this Branch participate in and coordinate on work load negotiations; perform analyses of production effectiveness, cost, and staffing requirements; and determine the work load capability. They provide assistance to the Production Engineering Branch on special projects, such as preplanning teams. LPPE personnel direct the production planning teams. They prepare the work authorization documents and develop the data for production equipment. They monitor the Division's ADP systems—including developing and monitoring policies and procedures to improve Division systems and then recommending changes and assisting in system design requirements.

In addition to its primary production planning responsibility, LPPE performs methods engineering and develops and maintains resource standards for labor, material, facilities, and equipment. LPPE personnel are responsible for engineering analysis, evaluation, and design of all proposed method improvements within the division. They review proposals for equipment, products, and industrial processes to determine application and acceptability. These proposals require extensive coordination because they may affect facilities, layouts, methods, resource standards, support equipment, and repair and test procedures.

In this function, LPPE personnel determine the requirements, establish the initial justification, periodically reevaluate the need for division equipment projects in the Depot Plant Modernization Program, and implement mishap prevention and fire prevention programs. In conjunction with the Safety Office at the ALC, they incorporate Occupational Safety and Hazards Act (OSHA) standards into production engineering projects. Projects under the Air Force Industrial Fund (AFIF) and the military construction program (MCP) originate in this Branch. The AFIF is used for the modification, addition, and repair projects for ALC facilities. MCP is the primary means of getting new construction or altering existing facilities when cost exceeds statutory limitations for Major Command approval and Congressional approval is required.

This branch controls the Value Engineering Program for the Division. Value Engineering is the formal technique by which AFLC contractors may voluntarily suggest (or be contractually required to identify) changes to weapon systems, equipment, facilities, services, or supplies that will result in increased reliability, maintainability,

interchangeability, product quality, and safety at the lowest life-cycle cost consistent with performance requirements.[22]

LPPE also develops the plant layouts and performs the human factors engineering studies to design the repair lines.[23] We were told that layouts are changed often, especially with the shutdown in work loads due to defense cuts—the space utilization has to change with the work load.[24] The repair lines are designed by taking the LSAR data, work methods, and standards, and developing a logic chart and a task chart. LPPE personnel analyze each task with a stopwatch and use the AF standards for routine tasks. The current computer system, PACER[25] FACTS (Fast Access to Computerized Time Standards)[26] asks the size, geometry, and material of the part and then produces a time answer. (In the future, this function should be part of DMMIS.) Because of its use of LSAR data and human factors analysis, this branch appears to have high potential as an HCT customer, but any development must take into account the PACER FACTS and DMMIS systems.

Facilities and Equipment Section. The Facilities and Equipment Section (LPPEE), or Facilities Engineering, develops the plant layouts and designs material handling fac'lities. LPPEE personnel develop data products to justify the purchase or replacement of production equipment, review proposals for equipment to determine application and acceptability, and determine the space requirements and needs for facilities and equipment. They initiate work requests for facility repair, maintenance, and installation. Facilities and Equipment works with Management, Scheduling, and Production Planning to determine the shop capability in the MISTR process.

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22 *Application for the President's Award for Quality and Productivity Improvement 1991*, Air Force Logistics Command.

23 The ALC repair process does not really involve repair *lines*, but repair *cells*.

24 We were told at OC-ALC that the Airframes Directorate won't be as affected by the cutbacks because it is bringing a lot of prior contracted-out work back in-house. The overall airframe load will probably increase in the future.

25 PACER is a designation or code that identifies a project or program as AFLC-owned.

26 The initial goal of PACER FACTS was to make labor standards easier to develop and maintain. Thirteen generic processes (e.g., parts cleaning, disassembly, painting) have now been identified for the development of standard data, covering a big percentage of work performed. Each ALC will develop data for several processes and share it with the other centers with the goal of making it easier to accommodate equipment and facilities changes. PACER FACTS, which should be used command-wide by 1992, reduces from 12 hours to 2 hours the time it takes to develop each hour of standard.

For example, in the Process Order for the "Plating of Gas Turbine Engines and Aircraft Components," Facilities Engineering is responsible for determining the requirements and need for facilities and equipment projects in the Plating Shop, initiating work requests for facility repairs; establishing periodic maintenance/inspection requirements for production equipment; providing assistance to the Production Engineering Branch on special projects concerning the Plating Shop; and performing utilization studies, methods engineering, and human factors engineering for the Plating Shop.

Facilities Engineering controls the Value Engineering program for the Division. Its workers develop and improve the depot repair processes and methods. They submit requirements to the Air Force MANTECH program. Projects under the Military Construction Program (MCP) also originate in this Section.

The process for designing a new line is lengthy. First, Facility Engineering has to make a case for renovating a line (capacity is a factor). It must write up a proposal, check all the alternatives, and do an economic analysis to get the funding. OC-ALC does not have the resources to administer a whole project unless it is small—perhaps one machine or a realignment. The Army Corps of Engineers, which has an office on Tinker Air Force Base, actually administers the project. The Corps hires an Architecture and Engineering (A&E) firm, which is usually a local design group, that takes the information, comes to the plant, and designs the new line. For small jobs, Facilities Engineering then does its own sketches (not allowed to do engineering drawings because they are not in this Section's domain) on paper or with the CAD system CADKEY. CAD is used primarily for shop layout, although the workers we spoke with told us that the available CAD *could* be used for modifications and design of equipment—it just isn't.

The number of projects varies with the number of large facilities (two projects in the past 5 years for OC-ALC Propulsion). Safety and hazardous material (HAZMAT) issues are usually the driving force. For example, operator access to tanks is important because poor access could be a safety hazard. The maintenance technician's access to parts is also important for safety. A safety analysis could be done with human performance or man models to investigate weight and balance if the models were easy to use and readily available.

Resource Standards Section. The Resource Standards Section (LPPER) develops and maintains resource standards for labor, material, facilities, and equipment. The functional responsibilities of the industrial engineering technicians in LPPER are

concerned mainly with planning, designing, analyzing, improving, and installing integrated work systems that comprise men, materials, and equipment used to produce products, render services, repair equipment, or move and store supplies and equipment. The activities can involve studies of engineering time standards, utilization and feasibility studies, layout design of work centers, control systems, material handling, or manpower utilization. The technicians perform methods improvements by analyzing work process elements to eliminate unnecessary motion and determine the most economical methods to accomplish tasks and operations. Again, the human-machine interaction that needs to be considered in these processes could be aided by HCT.

The functional responsibilities include—

- Workload Planning—establishing programmed work load and temporary work orders, developing initial Bill of Materials and flow and sequence charts, participating in provisioning conferences.
- Labor Standards—classifying labor, permanent and temporary work loads, MISTR, work place and work position layouts, and occurrence factor documentation.
- Flow day standards—flow process charts and critical path analysis.
- Material standards—permanent and temporary work loads, Work Control Document changes, TCTO changes and cost impact, SPC teams.
- Value Engineering and Method Improvement Studies.

c. Scheduling Branch (Engine Control Center)

The Scheduling Branch (LPPS) has over 200 people altogether, distributed among the major shops. One person per engine is involved in scheduling and the daily briefings. Scheduling works with Management, Facilities and Equipment, and Production Planning to determine the shop capability and with the Acquisition engineers and Production Planning to determine the supportability of consumables and expendables in the MISTR process. The Engineering Control Center schedules the overhaul of all the jet engines through all repair and assembly shops from overhaul requirements given to them. Scheduling has a yearly contract for a certain number of engines. For each engine, scheduling personnel break down the process from procedure to procedure. They monitor what should be done vs. what is accomplished, finding the bottlenecks and taking corrective actions.

Currently the Scheduling functions are all done manually, although there is a semi-automated inventory tracking system (ITS) that gives the locations and status of all the parts. Higher volumes of parts create problems with tracking the inventory. In the future the manual records are to be replaced by DMMIS.

The Production Controller serves as the single point of contact for the Propulsion Division on all scheduling functions related to the overhaul of jet engines and their components. Item flow is monitored continuously to ensure effective labor utilization and to prevent line stoppage and labor reassignment. Daily meetings are held with Production and Scheduling personnel. Monthly input/output schedules are developed based on available manpower, skills, and shop facilities; material supportability; and task priority. These activities also require communication with the Production Controller and personnel from the Management Division, Procurement, and Depot Supply.

C. CONCURRENT ENGINEERING AND THE LOGISTICS CENTERS

Many barriers to the implementation of Integrated Product Development (IPD) or concurrent engineering (or Integrated Weapon System Management, IWSM) surfaced in the opinions, attitudes, perceptions, and problems of individuals who work in the OC-ALC Propulsion Directorate. These are important to recognize because they will have to be overcome to achieve the vision of Integrated Weapon System Management (IWSM). While the Acquisition Logistics R&D Activity cannot help with the ALC budget problems, it can help with getting groups of people to work together through GST. With the advent of combined Commands in AFMC and the implementation of the IWSM concept, opportunities for concurrent engineering or IPD should be greatly enhanced.[27]

1. Interactions With Contractors and SPOs

In general, people at OC-ALC feel that they are not involved early enough in the development process, a situation to which they attribute daily problems once the weapon system becomes the responsibility of the ALC. OC-ALC management believes that early

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27 It is interesting to note that GE Engines, for which OC-ALC is the primary depot maintenance facility, is the prime contractor for the Defense Advanced Research Projects Agency (DARPA) Initiative in Concurrent Engineering (DICE). OC-ALC personnel said they had not heard of the DICE program. However, in the F-15 A/C program, logistics people from Warner-Robbins (airframe) and San Antonio (engines) were assigned to the ASD SPO.

involvement of "grass roots people" could save the ALCs and the Air Force a lot of money. However, travel budget restrictions currently do not allow sending people to the design contractor.

OC-ALC does keep lists of "horror stories" due to lack of consideration of reliability and repairability during the development of engines. These lessons learned are compiled and sent out to the acquisition people at Wright-Patterson Air Force Base (WPAFB). We were told that OC-ALC personnel who write the lessons learned do not know whether they are ever reviewed.

We were also told that the working relationship between the ALCs and the SPOs is not very good. The ALC people feel that the people selected at the SPO for the acquisition process are not experienced. In fact, we were told that the Deputy Program Manager for Logistics (DPML) may never have been to an ALC and may not know how such centers work; instead of having a logistics background, he or she may come from Supply or Procurement.

Early assessment of maintenance on new systems is part of the Logistics Support Analysis (LSA) review process. During development, ALC representatives may go to the LSA review meetings but they are "self-invited guests." The ALCs believe that the contractor does not want them attending the reviews, and no money is provided from the SPOs for the ALC attendance. We were told that ASD owns the engine, that the field is the customer, and that the ALC is perceived only as another contractor (it is also felt that the AFSC views the AFLC as just a contractor for them). Consequently, the ALC participates in the LSA process on its own and receives no funding for it. In short, the interviewees felt certain that the SPOs won't fund early involvement of the ALCs in the process. For IWSM to truly work, this situation must be alleviated.

The problem with the quality of the Tech Orders surfaced repeatedly during our visit at OC-ALC. The contractor writes the Tech Orders and gives them to the Air Force to verify; however, we were told that in reality the ALC ends up rewriting them and adding additional information. The contractor is supposed to know the facilities, processes, and capabilities that the ALC has because the contractor is required to do a Site Survey Facilities Plan. The Tech Orders should correspond to the facilities but in general they do not. The CIP also requires a mini site survey when procedures are added. Propulsion Management

has to work with the contractor during pre-production and production, but the product data are not available to them. People in this area said it would be beneficial if they could have access to the commercial data.

At an ALC, the Management Division manages the contract, the Product Division carries it out, Procurement keeps the parts in stock, and Supply supplies the items. There is evidence that the working relationship among different divisions, branches, and sections at an ALC may also suffer from lack of communication. The Product Division feels that the technical service engineers are not much support to them—they have difficulty figuring out what the TS people have written and hinted that TS may really be in the position of blessing the recommendations of the Product Division. People at the OC-ALC said that the Management Division spends a lot of time in negotiations with the maintenance people in the Product Division. They shared a general feeling that they do not have enough tools available to efficiently do their job, and that they spend too much time putting out fires.

2. Interactions With Customers

The Organizational and Intermediate maintenance people at the SAC, TAC, and MAC bases are the customers of the ALCs. The ALC generally supports the Air Force mechanics, but people are sent out only to solve problems, never purely for communication purposes. Visits out to the field have been very restricted, and customer support visits have been discontinued due to the lack of TDY funding. This situation frustrates attempts to get things done. For instance, there may be miscommunication between the various levels of maintenance because the different levels of maintenance refer to items differently: Part Number, Control Number, Stock Number.

In addition, the ALCs are made up of mostly civilians and reservists and the Combat Logistics Support Squadron (CLSS) consists mainly of military people. This problem is reflected in a potential lessons learned submittal record concerning MAJCOM and ALC involvement in Integrated Logistics Support (ILS), Logistics Support Analysis (LSA), Maintenance Planning Group (MPG) and Depot Maintenance Activation Group (DMAG) meetings. The lesson learned was that MAJCOM and ALC representatives must be present at conferences/meetings where decisions are made that affect maintenance at organizational, intermediate, and depot levels. Such attendance would ensure that the positions of the field-level users and the Source of Repair (SOR) at the depot-level would be expressed to both ASD and to the engine contractor.

The Blue Two program takes designers and engineers of weapon systems to operational bases where they work with the airmen who actually do the field repairs. A large number of participants come from the contractor because of the reliance on them for redesigning and manufacturing many of the modifications.[28] People on Blue Two visits obtain practical comments on problems by actually talking with the field people, and they have the goal of improving the design for ease of maintenance. Such visits are also initiated when the system is not functioning properly. The Blue Two program appears to foster concurrent engineering.[29] However, Blue Two visits are no longer joint between the SPOs, the contractor, and the ALCs because of the new competition requirement.

The Management Division at OC-ALC talks with the National Guard almost every day on different technical issues, but communication overseas is especially difficult because of mechanical problems in the system and the time limit on the communication link.

3. Human Factors Analysis

At present, the experience and expertise of the people—or "Organizational Memory"—is the crux of Human Factors and Safety analyses. Logistics Support Analysis (LSA) is supposed to address this area during design, but time and money pressures pervert the process, as discussed in Section 1, above.

We were told that the Logistics Support Analysis Record (LSAR) contains basically assembly and disassembly instructions. The LSAR process is supposed to develop repairs, but the OC-ALC personnel said that it lags behind in the processes the ALC has to perform to develop repairs. Personnel at the OC-ALC even stated that the LSAR was a useless document to them. They said the only time the LSAR is really used is during the development stage of the engines—and then only for turning nuts and bolts. The Failure Modes and Effects Analysis (FMEA), which has to be developed from experience, has only a minor influence during engine development, although the LSA requires reports from the ALCs on what is done and uses that experience at some point.

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28 *Application for the President's Award for Quality and Productivity Improvement 1991*, Air Force Logistics Command.

29 The Blue Two Visit Program and engine mock-ups were both used to determine maintainability of the ATF engines. The ATF engines are the first ones with a contractual requirement to be delivered with repairs from the contractor.

Human factors for maintenance and repair are not formally accounted for in acquisition, but addressed during prototype verification and CIP-proofing (for modifications). Management addresses human factors in the statement of work of the CIP. Human factors problems in maintenance and repair (assembly and disassembly) are addressed as a TO problem, not a design problem since repair, maintenance, and overhaul, are documented in the TOs.

There is almost a daily feedback on HF problems from the field. Most of the frequent problem reports are not on maintenance problems per se, but on safety issues (Safety Caution Notes, Safety TCTO). We were told that maintenance problems identified in the field could have been prevented if the proper human factors considerations were taken into account at the proper time (e.g., bomber maintenance in Alaska in winter apparently had some problems with winter clothing & material handling in the cold).

4. Use of New Technology

We were told at OC-ALC that the ALCs are approximately 5 to 10 years behind industry in their acquisition and use of new technology. OC-ALC still uses World War II era equipment; Pratt and Whitney and General Electric (the contractors) have much more modern equipment.[30] The need for automation of the lines, however, is not clear. Most of the repair is done manually because many different parts of many different engines are being repaired at one time—automation is most effective for the repair of a great number of single parts at one time. Without automation the need for consideration of the human interface with the equipment will be needed far into the future.

A Flexible Repair Center (FRC), which is easily reconfigured to allow automation for the repair of different parts, was purchased by OC-ALC at a cost of several million dollars. Even though budgets exist to upgrade facilities, the purchase of the FRC required a lot of money from a lot of different projects. The FRC is currently being used to prototype four to five items, which is significant for OC-ALC. According to people there, although the overall work load is decreasing, new work loads will be shifted to the FRCs.

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30 Under the QP4 quality program, OC-ALC is now benchmarking with the American Airlines Maintenance Facility in Tulsa, OK, for engine and engine component remanufacturing. We were told that they felt far behind American Airlines in modern technology.

New engines will require fewer hours of maintenance, however, and will be more reliable. The main work load for the FRC will probably remain for the complex, old, non-CAD engines.

The FRC would normally function with CAD data. Since the ALCs don't have CAD data for the current engines,[31] the FRC is used in an NC (Numerical Control) mode rather than with CAD. NC code (computer programs) has to be written in order to be able to use the FRC for the non-CAD parts—the engineers cannot feed directly into the FRC. Producing CAD-type data from non-CAD parts is very labor intensive, and the information is not being put into a CAD data base. New systems designed on CAD would save time—but how many new systems will there be?

CAD is primarily used for process planning, facility layout, and repair cell design, where safety is a primary driver, but currently there are no computerized tools to plan or model the repair processes.[32] The OC-ALC Commodities Directorate uses several NC machines, mostly for manufacturing. Only one machine other than the FRC is NC capable in the Propulsion Directorate at OC-ALC.

5. Use of Computer Systems

We felt a distinct hostility to computers and a resistance to any new system at OC-ALC. OC-ALC has formed a Small Computer Division that is looking at Voice Activation as an alternative to keyboarding to reduce the hostility.[33] We were told that the use of computers at OC-ALC is limited for the following reasons:

- Low availability (too few of them).
- Difficult software.
- Resistance in current culture.
- Lack of staffing.
- Lack of training.

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31 It is expected that 3-D CAD information will be available for the B-2, ATF, F-17.

32 They expressed some hope that CAD/CAM information would be available in the future through CALS.

33 The Groupware community is also looking at voice-activation technology, a fact that should not be ignored if the Acquisition Logistics R&D activity is going to develop Groupware for the ALCs.

OC-ALC has widely varied needs, but people there said that too many different, incompatible computer systems are located throughout. We were told that acquisition or development of these systems (hardware and software) is not well planned,[34] and that funding is the major roadblock. The engineers in the Management Division felt that everyone should have a terminal at their disposal, but that the budget has been cut so much there just isn't enough money for the computer support needed. They have problems justifying new technology—managers need to see results before committing funds up front. In fact, funds for new systems are always reduced because of a lack of top management commitment. EDCARS (Engineering Data Computer-Assisted Retrieval System)[35] is used and OC-ALC engineers use some CAD, but drawings are generally produced manually. LPA felt that CAD would be helpful to the engineers if it were available; however, there are too few drawings to justify it. Contractors do furnish some tools to the OC-ALC to do engine assembly/disassembly analysis functions. The CAD system CADKEY resides on only one machine (a contractor's) for all of OC-ALC/LPA, and personnel in this Division told us it was difficult to use, owing to all of the reasons listed above.

Some of the reasons for the limited use of computers are reflected in the comments about DMMIS. We heard complaints that the existing data system requires too much data to be entered and updated, using up needed resources, and that DMMIS will actually increase the data required. We heard statements that the "systems make us respond to them" instead of vice versa, and "DMMIS will require us to supply data that we don't even use." DMMIS is supposed to tie everything together to avoid manual data transfer and keep everyone up to date. However, it was felt that the DMMIS system developers have no concept of the ALC's narrow focus. "The DMMIS system developers appear to be deaf to the problems. The high-level people don't understand the nuts and bolts." OC-ALC personnel said that the system didn't seem to satisfy repair needs, and they feared that it would be forced on line too early. They stated that the data base has to be done right to be useful to them, but problems with the local data base already exist. Factors and values have to be identified correctly while the data base is being developed. The right factors and

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34 Daryl Jacoby, *Potential Lessons Learned Submittal Record*, MAENA, 31 July 1989.

35 EDCARS allows digitized engineering data to be stored in the form of rasterized images on optical disks using laser technology.

values have to be found early to avoid fragmented data—some factors and values may be unknown today for inclusion in the data base, but the ALC may find out later that in reality they are important. Data generation occurs too late once the system gets to the ALC; it has to be done beforehand. Initial input should be done by the contractor.

6. Training

The restructuring and reduction of manpower that is occurring throughout the military is also occurring at the Air Logistics Centers. This is a time of DoD hiring restrictions, relatively noncompetitive salaries compared with those of industry, and a rapid pace of technological advances. We were told at OC-ALC that keeping trained people is very difficult, and that there is concern even when people move around in the plant itself. The Center must expend considerable effort to retain the expertise it has and to retrain employees if feasible. The defense industry also views the loss of corporate knowledge as a major problem in relationship to concurrent engineering, which requires a number of experts to do the job. Losing expertise in the middle of a project—even because of promotions—can be catastrophic.

The training problem is one that also occurs among defense contractors. Processes are more complex today than in the past, and lesser educated people are becoming much more difficult to train. We were told at OC-ALC that the production equipment does not come with training manuals, and that writing training procedures for all the different levels of education at the ALC is extremely difficult.

7. Use of Teleconferencing

The Management personnel expressed the need to talk to people (the contractor, the SPO) face to face. They said that if they cannot attend meetings due to lack of TDY funds, they cannot get anything accomplished. Currently they rely on the phone, faxes, e-mail messages, and teleconferencing to get the business done.

The interviewees also expressed strong resistance to the use of the teleconferencing facility at OC-ALC. They related a bad experience with a teleconference with Hill AFB (Ogden ALC). They said the computer was often down and people fell asleep. They felt such meetings lacked the human dynamics of face-to-face meetings. Scheduling a TC appears to be difficult because there is only one facility and meetings have to be locked into

time frames and schedules. Because there is only one teleconferencing facility for the whole ALC, a high-level person is always in the room during its use and people are inhibited from saying what they really feel.

One justification for a TC is that it will reduce travel expense;[36] however, we were told that "machines never replace face-to-face."[37] When asked about video conferences or groupware for a distributed meeting, the interviewees saw a big problem with security and classified information. Management does have to meet to discuss issues with the contractor approximately once a month, and they said that video with real-time graphics transmission would be helpful in that context.[38] GE representatives at OC-ALC have this capability in the form of a "photo phone." They did say that video technology would be helpful for training and reference. OC-ALC is now requesting that the contractor videotape the maintenance and repair procedures,[39] and they told us that a computer demo to teach the operations of the machines would be very useful.[40]

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36 When we spoke of this development to the GD Convair engineers, their reaction was that travel is still relatively cheap in the light of what can be accomplished during a face-to-face meeting.

37 It is interesting to note that on our visit to General Dynamics, Convair Division, we heard the opinion that it was a mistake to reduce TDY to save money and resort to teleconferencing. Travel is still relatively cheap and face-to-face meetings will never be replaced.

38 They said that current faxed sketches are OK, but better graphics is desirable.

39 GE validations are now taped and submitted.

40 Seems like a perfect application for Digital Interactive Video (DVI).

VI. ENABLING KNOWLEDGE AND TECHNOLOGY FOR HUMAN CENTERED TECHNOLOGY

Current CAD/CAE approaches to human factors assessment, especially human models, use computer graphics technologies to specify and to display human performance capabilities through video representation. The term "computational human factors" describes the general trend toward the use of computers, and especially computer graphics, to represent human/machine performance. In these applications, human form (i.e., physical) and human process (i.e., cognitive) models replace or supplement the hardware mock-ups, simulators, and prototypes traditionally required to perform task-analysis analyses during system design.[1]

Three important benefits are gained by integrating human-centered design evaluation with modern design technology and logistics information processes. The first is design interaction. The solid model or CAD link should permit earlier, more accurate, and more economical evaluations of the human/machine interface. It is easier to change equipment designs when problems are detected early, before the design is fixed and hardware is fabricated, and it should be easier to persuade designers using the visual medium of computer graphics.

The second benefit is in achieving design concurrency. Integration around solid modeling, CAD, and CAE should allow human-centered issues to be evaluated simultaneously with other engineering and logistics support specialty engineering functions. The design engineering cycle should become less costly and time consuming, and more supportable products should result. This is a central objective of integrated product development (IPD) and concurrent engineering.

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1 Much of the detailed technical information in this chapter was provided by Ed Boyle of the Armstrong Laboratory, Human Resources Division, Logistics Research Branch, at Wright-Patterson Air Force Base. Particularly, information was taken from his forthcoming paper, ***Human Centered Technology: Ends and Means.***

The third benefit is in linking with CALS-oriented design support information through the established Logistics Support Analysis (LSA) process. The rationale for integrating CALS with HCT is to create a design support data base in digital format—without paper—that contains more complete and more accurate documentation of the human centered aspects of system maintenance.

A. HUMAN-MODELING

Human Centered Technology (HCT) includes human models. To date, the human models have focused on the physical or ergonomic aspects of human/machine interaction. Kroemer et al. divide these models into anthropometric, biomechanical, and human/machine interface types.[2] In short, the human models are intended to help answer questions about the equipment or workplace such as:

- Can the human model fit into it? (anthropometry)
- Can the human model move or reach well enough? (kinematics)
- How much force can be applied? (biomechanics)
- How well can the human model see? (visualization)

Evaluation of these and related physical aspects of human/machine design have been greatly facilitated by the use of computer graphics-based representations of the human figure within the proposed workspace.

When these models are used to incorporate human factors into system design, the customer or end user of the models is a concurrent engineering or IPD team member. This team member could be a designer, but will more than likely be a specialty engineer for human factors or maintainability analysis, who is connected to the designer's CAD system through an integrated framework or through a group support system (GSS) as described in Chapters IV and VII. These models will be beneficial for product development only if the concurrent engineering team has confidence in the models and can use them easily and quickly. It would be counterproductive to use tools that produce wrong answers, and it would be inefficient to spend more time entering data and using the model than would be spent in a manual or some other automated analysis. The same problem exists with

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2 Karl H. E. Kroemer, Stover H. Snook, Susan K. Meadows, and Stanley Deutsch, eds., *Ergonomic Models of Anthropometry, Human Biomechanics, and Operator-Equipment Interfaces: Proceedings of a Workshop*, National Research Council, Washington, DC, 1988. (Hereinafter referred to as *Ergonomic Models.*)

"lessons learned" data bases: Designers are unlikely to consult them for each design decision if they are not structured for efficient use.[3]

Developers of human models and human performance models for use in product development must take into consideration the requirements of the product development team. The concurrent engineering team's requirements may differ substantially from the traditional reasons for developing these models: increasing basic knowledge of human performance or improving modeling techniques for their own sake.[4] To satisfy a concurrent engineering team's requirements, these models must—

- Be applicable to the problem being solved
- Produce correct results
- Be easy to acquire and use
- Not cost so much as to preclude their use.

1. Current Human Factors Uses of Human-Modeling

a. Physical Models

A large number of human-modeling techniques have been developed. Kroemer et al.,[5] Hickey et al.,[6] Rothwell,[7] Hidson,[8] and Richards and Companion[9] provide detailed

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3 R. Bruce Gould, AFHRL/MOD, MPT Technology Branch, Brooks AFB, TX, and Thomas Nondorf, McDonnell Douglas Corporation-MCAIR, St. Louis, MO, panel discussion "Design for Maintainability" in: Edward Boyle et al., eds., *Human Centered Technology for Maintainability: Workshop Proceedings*, Armstrong Laboratory, Human Resources Directorate, Logistics and Human Factors Division, Wright-Patterson Air Force Base, OH, January 1991. (Hereinafter referred to as *HCT for Maintainability*.)

4 Jerome I. Elkind et al., eds., *Human Performance Models for Computer Aided Engineering*, National Academy Press, Washington, DC, 1990. (Hereinafter referred to as *Human Performance Models for CAE*.)

5 Kroeme et al., *Ergonomic Models*.

6 D. Hickey and M. Pierrynowski, *Man-Modeling CAD Programs for Workspace Evaluations*, Defence and Civil Institute of Environmental Medicine, Downsview, Ontario, 1985.

7 P. Rothwell, *Use of Man-Modelling CAD Systems by the Ergonomist* (DCIEM 85-R-26, AD-B095078), Defence & Civil Institute of Environmental Medicine, Department of National Defence (Canada), July 1985.

8 D. Hidson, *Computer-Aided Design and Bio-Engineering: A Review of the Literature* (Technical Note 88-31), Defense Research Establishment, Ottawa, July 1988.

9 J. Richards and M. Companion, *Computer-Aided Design and Evaluation Techniques (CADET)* (AFWAL-TR-82-3096), Air Force Wright Aeronautical Laboratories, Flight Dynamics Laboratory, Wright-Patterson Air Force Base, OH, 1982.

descriptions and comparisons of SAMMIE (System for Aiding Man-Machine Interaction Evaluation), PLAID/TEMPUS (not an acronym), CAR (Crewstation Assessment of Reach), COMBIMAN (COMputerized BIomechanical MAN-Model), and Crew Chief, among others. Most human-models create whole-body representations using a basic link system, which is a simplified version of the human skeleton. Enfleshment algorithms can be used to create a more realistic illusion of the human form, and CAD rendering techniques can be used to make the display more visually compelling. In addition, many human-models use CAD graphics techniques to change the angle of view, to zoom in on a particular part of the computer screen, and to generate three-dimensional displays. In every case, an adequate anthropometric data base is required for the construction of human-models.

b. Pilot-Operator Models

Another focus of human-modeling simulation has been the performance of the pilot-operator in the cockpit-workstation. For example, in the A^3I program (Army-NASA Aircrew/Aircraft Integration), and the Human Systems Division's (HSD) Cockpit Automation Technology (CAT) program, attention falls on integrating visual and cognitive information processing requirements with human-modeling simulation for pilot-operator work load assessment. Elkind et al.,[10] Edwards et al.,[11] and McMillan et al.[12] provide detailed reviews of these and similar efforts. Baron et al.[13] describe numerous human performance process models (HPPMs), again focused on pilot-operator cognitive work-load assessment, including the Human Operator Simulator (HOS). New work funded by the Army Research Institute is attempting to link HOS, a task networking tool called MicroSAINT, and an anthropometric model to create an integrated human-modeling technology.

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10 Elkind et al., eds., *Human Performance Models for CAE.*

11 Jill Easterly, *Crew Chief: A Model of a Maintenance Technician* (AIAA-89-5043), AIAA/NASA Symposium on the Maintainability of Aerospace Systems, Anaheim, CA, 1989. (Hereinafter referred to as *Crew Chief Model.*)

12 G. McMillan, D. Beevis, E. Salas, H. Strub, R. Sutton, and V. Breda, eds., *Applications of Human Performance Models to System Design*, Plenum Press, New York, 1989.

13 S. Baron, D. Kruser, and B. Huey, eds., *Quantitative Modeling of Human Performance in Complex, Dynamic Systems*, National Academy Press, Washington, DC, 1990.

c. Maintenance Models

Among the CAD-based human models, only one, Crew Chief, deals specifically with Air Force equipment maintenance issues.[14] This software package presents a three-dimensional computer graphics model of a maintenance technician interacting with a CAD-defined work environment. A number of body sizes and postures, accurately scaled to reflect the Air Force maintenance work force, can be simulated. Available analyses include reach, visual and physical access, and strength characteristics of Air Force maintainers in various body postures. Use of common hand tools is also simulated. The model is supported by an extensive anthropometric data base describing both male and female populations. Crew Chief has been interfaced with CADAM and Computervision CAD systems so far. Details on Crew Chief technology and applications are found in Easterly,[15] McDaniel and Hofmann,[16] Korna et al.,[17] and Easterly & Ianni.[18]

The next section describes some of the limitations of human models and attempts to explain why these models are not used more often.

2. Limitations of Human Models

To make human models more useful to the concurrent engineering team, it is desirable to identify the limitations of current models from the perspective of the user. The perspective of the concurrent engineering team in evaluating human models may be quite different from the perspective of the model builder or researcher. In order to improve existing models or build new models that satisfy the designer as customer, general limitations in the areas of applicability, validity, and usability must be addressed.

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[14] Crew Chief is jointly developed by the H.G. Armstrong Aerospace Medical Research Laboratory and the Air Force Human Resources Laboratory, Wright-Patterson Air Force Base, OH.

[15] Easterly, *Crew Chief Model.*

[16] J. McDaniel and M. Hofmann, "Computer-Aided Ergonomic Design Tools," in H. Booher, ed., *MANPRINT: An Approach to Systems Integration*, Van Nostrand Reinhold, New York, 1990.

[17] M. Korna and J. McDaniel, *User's Guide for COMBIMAN Programs Version 7 (Computerized Biomechanical Man Model)* (AFAMRL-TR-85-057), Air Force Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, OH, 1985.

[18] Jill Easterly and John D. Ianni, "Crew Chief: Present and Future," AFHRL/LRL WPAFB, OH, in Boyle et al., eds., *HCT for Maintainability*.

a. Application to General Design Problems

The first area to address is the applicability of a model to the specific design problem under consideration. Current human models tend to apply to specific systems (like aircraft cockpits or even the cockpit of one particular aircraft) rather than to general design work. The models may be very applicable to one system or part of one system but not applicable at all to others. Thus, the team would require a number of models in order to analyze human performance related to every aspect of a design. Concurrent engineering needs integrated and adaptable ergonomic models to satisfy all or most of the human factors modeling needs,[19] and it could also use models that address the different phases of design detail—conceptual, preliminary, detailed.

b. Validity of Results

The next area to address is the validity of the results produced by human models. Clearly it is necessary for the models to produce valid results before they can be used to support engineering design. Rouse and Cody[20] found that designers and researchers were generally confident of the results models produced because most models are derived from actual measurements of human performance. Other researchers have questioned the validity of the human models in the absence of rigorous validation and verification.[21] Difficulties have been noted in particular with regard to relating model assumptions, parameters, and attributes to empirical data. This problem could be mitigated by the collection of additional data, but that process could be very expensive and time consuming. Some of the cost could be alleviated if model builders used government (mostly military) data to support the models.

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19 Kroemer et al., *Ergonomic Models.*

20 William R. Rouse and William J. Cody, "Designers' Criteria for Choosing Human Performance Models," in: Grant R. McMillan et al., eds., *Application of Human Performance Models to System Design*, Plenum Press, New York, 1989.

21 Barry R. Smith, "Six Years into the A^3I Program: Progress & Problems," NASA Ames Research Center, Moffett Field, CA; Nondorf, panel discussion; both in Boyle et al., eds., *HCT for Maintainability.*

c. Ease of Use

The usability of human models is another important area in which some problems exist today. The models are typically used to assess the performance of a human being as either an operator or a maintainer of a system, as models generally simulate tasks that make up system operation or maintenance. One of the principal difficulties of using current human models is generating tasks from high-level goals. The user cannot issue a command like "change an engine" to a simulation model and expect the model to generate all of the actions that the human maintenance technician must perform. The model user must laboriously generate task actions and arduously enter the data. Transparent data transfer among data bases would be helpful in this matter. Generating tasks is complicated by the absence of a task taxonomy—different terms are used by different people to describe the same actions. Furthermore, generating tasks requires detailed design information which is not available until the design is rather advanced. As a result, the model cannot be used early in system design.[22]

d. Specific Example

As an example, a number of enhancements that would improve Crew Chief's value in design evaluation have been identified. These include, in addition to task animation, an improved vision capability, simulation of multi-person maintenance tasks, assessment of environmental stressors, and detailed modeling of hand movements. The specific limitations and proposed solutions can be examined to help generalize to further development of HCT. The following discussion draws from papers written by two of the builders of Crew Chief and a user at the McDonnell Douglas Corporation.[23] McDonnell Douglas installed the first production release of Crew Chief and used it on the Advanced F-18 project.

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22 ibid.; Richard Pew, BBN Systems and Technologies, Bolt, Berenek & Newman, Inc., Cambridge, MA, panel discussion in Boyle et al., eds., *HCT for Maintainability*.

23 Easterly and Ianni, "Crew Chief: Present and Future"; Anthony Vrbensky, "Lessons Learned Implementing Crew Chief," McDonnell Douglas Corpcration-MCAIR, St. Louis, MO, in Boyle et al., eds., *HCT for Maintainability*.

The performance of Crew Chief could be enhanced by adding the following capabilities:

- Modeling of multi-person tasks, since most maintenance tasks are multi-person tasks.
- Random generation of proportions (the manikins in Crew Chief are of a single proportion; that is, they can represent individuals of different sizes but not of different proportions).
- Adding more variety of body postures or giving the designer the ability to move individual body parts.
- Automatic, detailed, hand-modeling and vision-modeling.
- Expanding the analytic criteria to include perceptual and psychomotor abilities required to do the task.

In addition, since Crew Chief has not been formally validated, a user cannot be sure that the results it produces are correct.

Crew Chief could be made more usable if tasks could be composed automatically, rather than by the user having to specify each individual movement of the technician. Far less work would be required to generate tasks. Crew Chief would also be improved if it required less computer memory to run all of its capabilities at once; in its current state, it may overload a CAD system.[24]

While Crew Chief is a useful model, it does exhibit some of the limitations described for human models in general. It could be made more realistic and applicable to more system designs by adopting some of the suggestions above. Adding these capabilities would serve to expand the potential community of users of Crew Chief and HCT in general.

[24] This problem with Crew Chief being integrated into the CAD system was addressed by he GD Convair engineers in Chapter IV.

3. Potential Improvements to Human Models

Having discussed the requirements of the concurrent engineering team using human models and the limitations seen in the current generation, we proceed in the following sections with a discussion of improvements proposed in the human modeling research community for making the human models more attractive to designers. This section will address first the performance of human models, then their usability.

a. Greater Breadth and Depth of Data

Human models can only be as good as the data that support them. Some researchers have recommended that model builders collect more data or use data more explicitly connected to the quantities used in the models.[25] Data requirements for advanced human models are more demanding than past needs for human data. For example, computer graphic simulations may require three-dimensional data that were not of interest to those studying human anthropometry in the past and therefore were not collected. The more copious and specific the data, the greater the realism of the models. Roebuck recommends that surveys should be done for the "new purposes of obtaining integrated, comprehensive and specific data needed for human modeling by graphic human analysis. . . . Work space evaluation needs are increasingly different from the original anthropological goals of comparing racial groups or even later needs for design of clothing."[26] In the absence of data, model builders must make estimates. If models are to realistically portray human motion performance, they need more support from the human factors data base including empirical data, guidelines, and case studies.[27] Even where data exist, they may not be applicable to the population of operators or technicians needed to be considered in system design. For example, much of the human factors data represent male members of the U.S. armed forces. To increase the range over which human simulations can be used, a complete data base representing the entire American work force is needed.[28]

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25 Elkind et al., *Human Performance Models for CAE*; William J. Cody and William B. Rouse, "A Test of Criteria Used to Select Human Performance Models," in McMillan et al., eds., *Application of Human Performance Models to System Design*, Plenum Press, New York, 1989.

26 John A. Roebuck, Jr., "Overcoming Barriers to Computer Human Modeling in Concurrent Engineering," Roebuck Research and Consulting, Santa Monica, CA, in Boyle et al., eds., *HCT for Maintainability*.

27 Elkind et al., *Human Performance Models for CAE*; Cody and Rouse, "A Test of Criteria."

28 Gould, "Design for Maintainability."

b. Standard Definitions for Data and Model Parameters

In addition to collecting more copious or more relevant data, the human factors community needs to develop standards for definitions of units, measures, measurement methods, and data reporting. If everyone in the human factors community does not speak the same language, it will be difficult for model builders to gather and use data collected by different people using different means.[29] Furthermore, it will be difficult for users to select correct values for model parameters without having clear definitions of them.

c. Generalized Application

The current generation of human models is limited in that the models are generally built to analyze specific tasks or systems. The analyst must find the particular model applicable to the particular system or subsystem they are considering in order to analyze the human tasks associated with it. The current context-specific models are not perceived to be applicable to other uses.[30] A general purpose, integrated anthropometric, biomechanical and human-machine interface model could be very useful in concurrent engineering for the analysis of operator and maintenance technician performance for one or a number of different systems. The model could merely be integrated with the CAD/CAE system through the integrated framework and used.[31]

Specific qualities, either existing in a current model or having the potential for future development, that are most desirable in a general purpose, integrated model include the following.

Three-Dimensional Dynamic Simulation. Surveys of system designers have indicated that an integrated human performance model should basically be a three-dimensional dynamic simulation.[32] Real people and real objects are three-dimensional. A dynamic model can account for the effects of human and platform motion. Simulations (as opposed to analytical models) allow designers to see cause and effect relationships of design elements.

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29 Kroemer et al., *Ergonomic Models.*

30 ibid.

31 Concurrent engineering decision makers also need different levels of human factors support that may not require such a detailed model.

32 Kroemer et al., *Ergonomic Models*; Elkind et al., *Human Performance Models for CAE.*

Multi-Person Task Modeling. An integrated model should be able to simulate tasks requiring two or more people to perform, as many system maintenance tasks require. The model should be able to account for the different sizes and proportions of people within the population of interest. The user should be able to move and position the human model freely within the CAD representation of the system.[33]

Psychological Aspects of Human Performance. In addition to the physical aspects of human performance, a complete, general purpose model would also address the psychological aspects of the performance of complex tasks. Some current modeling efforts are beginning to take human psychology into account. Hard science technologies and data (human factors engineering) are generally more mature than the soft science (cognitive) technologies and data, so this is an area in which research remains to be done.

d. Validation

After model builders create an integrated model, they need to validate it against measurements of actual human performance. Validation is an aspect of human performance modeling that has not been emphasized in the past. Consequently, the models have had limited utility for product development. If a model is not validated, there is no way to determine whether the data produced by the model is acceptable.[34]

e. Usability

While the performance of human models has the greatest effect upon their adoption by a concurrent engineering team, usability is also very important.[35] The concurrent engineering team members and their management need to see human models as tools that make their work easier or faster—the models must be both efficient and cost effective. Ideally, the concurrent engineering team members should be able to use all of their tools at the same time using a shared, distributed data base. CAD systems, mathematical dynamic models, and human models need to be integrated through a framework so that they use the

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33 Vrbensky, "Lessons Learned."

34 ibid.; Kroemer et al., *Ergonomic Models*; Elkind et al., eds., *Human Performance Models for CAE*.

35 Roebuck, "Overcoming Barriers."

same, standard, languages and interfaces.[36] Graphical concurrent engineering workstations will be needed to filter all of this information. The results of all of the analyses must pass through the same filter for the messages to be received by the designer with the configuration control for the design.[37] Moreover, since designs and design decisions must be documented throughout the design process, an integrated human model must allow the user to do so easily on line.[38]

In addition, some of the ultimate uses of the results of human task analyses are in the planning to meet manpower, personnel, training, and safety (MPTS) requirements. Advances in "hard" human factors technologies like human modeling have a positive effect on work in the areas of MPTS. Advances in soft MPTS technology, which is now behind the human factors technology, may change what is required from human factors to do MPTS planning. Human factors engineers should leave room in their future software to accommodate future improvements in MPTS.[39]

As noted in Chapter I, Section C.2.a, the function of a specialty engineer on a concurrent engineering team has changed from that of checking the design to actually recommending changes to the configuration control designer. Thus, human factors assessment should move from a merely descriptive level (i.e., "Something might be wrong") to a prescriptive level (i.e., "Something's wrong and here's how to correct it"). Easy access to relevant design goals and practical human performance criteria would allow a design check for human performance to be made. Work-around measures that can overcome identified design deficiencies are also needed. It is not enough to merely display a simulated task performance. The analyst needs to know whether the predicted performance meets preestablished design goals or exceeds known human performance limits before he or she can determine that a design is good or bad. Such indicators are lacking in most current human factors simulation technologies. Potentially relevant human performance information is abundant, but scattered—it needs to be brought together to make it useful.

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[36] Brenda Thein, "Human Performance Modeling: An Integrated Approach," U.S. Army Human Engineering Laboratory, Aberdeen Proving Ground, MD, in Boyle et al., eds., *HCT for Maintainability*.

[37] Gould, "Design for Maintainability."

[38] Kroemer et al., *Ergonomic Models*.

[39] Gould, "Design for Maintainability."

B. KNOWLEDGE AND TECHNOLOGY DEVELOPMENTS

Expanded human factors evaluation criteria include, in addition to physical abilities, estimates of related perceptual and psychomotor abilities underlying task performance. Maintenance job design and training decisions would be much better supported if there were ways to accurately predict these non-physical ability requirements through human-modeling methods. Human-modeling needs to move up to the higher level human factors involved in overall job design and work force planning. Estimations of a fuller range of human performance criteria, not just physical criteria, are needed to make this possible. Human/machine interactions must be displayed in greater detail and with greater realism than they are now. This enrichment will come from the integration of CAD-based equipment design information, computer graphics and animation technology, and the automation of human performance and human resources data applicable to the proposed human/machine environment. The ability to combine visual and non-visual task information underlies the advanced task analysis capabilities needed. Technology developments in CAD technology, human figure modeling, data base integration, and knowledge base representation technologies will help reach this objective.

1. CAD and CAE Technology

a. Workstation Technology

A computer graphics workstation will provide a versatile platform for the development, demonstration, and transition of computer graphics human-modeling technology. An open workstation architecture will allow new or improved analysis methods to be readily incorporated and will also support an incremental, phased approach for technology transition to users. For many reasons, it is desirable for HCT to adopt common data architectures and interoperable software/hardware platforms. Modular software design will provide a flexible and efficient means of updating and integrating new or modified applications programs. Human performance analysis procedures and data bases embedded within or integrated with the computer graphics workstation will aid the task analysis process and provide a design diagnostic capability. The human factors analyses would be organized around a core human-model program resident within the workstation. The HCT workstation will interface with commercially available solid modeling, CAD, CAE, CAM, and LSAR systems through the framework (see Chapter IV).

b. Design Advisor Capability

The user should be able to quickly find out how a particular task and task environment are viewed in scientific literature and other applicable information. In this way, the analyst could quickly determine whether relevant design or human performance criteria are violated, and by how much. A design check to confirm human performance capabilities is needed for practical task evaluation. The user must be able to find out which science, experience, or design requirements apply to a task design to determine the fitness of the design. This implies a need for a workstation utility that can act as a design advisor to help in solving task specification, task analysis, and task evaluation problems. Much work is being pursued in this area, often under the guise of expert systems, with very specific applications.

c. Computer Graphics Visualization Technology

New opportunities have been created by a rapidly developing array of computer technologies, particularly in the computer graphics field. For instance, it is now possible to create detailed, accurate, and realistic simulations of work through human figure animation. Advanced animation technology, if it can be economically added to current human-modeling capability, would greatly enlarge the task performance information available to the expert analyst during engineering design.

Graphics/animation technology, especially for accurate simulation of humans, and especially for simulation of human movement, needs to be developed for these ends. Such technology should permit the display and evaluation of a wider set of human factors/human performance criteria and should allow simulation of entire task sequences through animation techniques. More relevant detail and environmental stressors can be introduced through CAD graphics "rendering" and related software arts. The analyst (and the designer with the configuration control) must be able to view a proposed design and look at an actor doing something. With graphics technology, there is visual evidence backing up a design evaluation, not just a verbal report. The power of the graphics technology is in task visualization to verify problems and solutions in human/machine integration.

The limiting factors to task analysis appear to be the degree of accuracy, detail, and realism that advanced computer technology can provide. For this purpose, the ability to animate the simulated worker and work environment—that is, to introduce realistic movement to the simulated display—is an important new requirement and opportunity for an effective computational approach to task analysis and human factors evaluation. Computer graphics technology for task animation should allow visual assessment and confirmation of task performance. An ideal technology for this purpose would have the following characteristics.

Accuracy. An animated human model should accurately replicate relevant human anthropometry, biomechanics, and movements. Interactions of the animated human-model(s) with the modeled work environment should appear to be natural. Equipment and/or workplace setups should be accurate representations of the relevant design features.

Detail. An animated human model should be portrayed in sufficient detail to permit confident description of human abilities and task performance requirements. The work environment should be imaged in sufficient detail to ensure that the relevant human/machine interactions (e.g., equipment repair) can be portrayed. For example, the analyst should be able to call up special purpose models for close-in viewing of fine motor tasks or of tasks having high demands for visual discrimination. In addition, the analyst should have ready access to relevant information applicable to the task performance environment to assist in task specification, simulation, and evaluation.

Realism. An animated human model should behave purposefully according to a logical plan of action. He or she should be capable of acting out task sequences in realistically timed motions. The human model might appear to react, plan, detect obstacles, avoid uncomfortable or inefficient postures and movements, and so on. In short, the artificial person should appear to have a sort of artificial intelligence.

2. Human Figure Modeling Technology

Human figure modeling technology is advancing rapidly. Realistic, accurate depictions of operators and maintainers interacting with prime equipment, support equipment, and the work environment can be created. The ability to display a complete maintenance task, or sequences of tasks, through computer animation is a process called

automatic task composition. This should permit broader estimation of both physical and non-physical aspects of task and job requirements than current methods permit. Dynamic simulation of maintenance tasks using advanced human-modeling and animation technologies will provide a powerful visual medium for design evaluation and design influence.

Better capabilities to simulate and analyze human hand movement and visibility, multi-person tasks, and the effects of environmental stressors on physical workload and performance are needed. Manual skills are required and many tasks require more than one person to perform safely. Different lighting and environmental conditions are often encountered in the real world. Hence, task analysis using human-modeling technology will benefit greatly from more realistic representation of these real-world working conditions. Technologies for some of these requirements are being developed, but they are not yet found within a single modeling environment.

Matching physical characteristics of people to work requirements using CAD-based human-models is a technology nearing maturity. This is not to say that the technology is complete or perfect. Indeed, much remains to be done in the ergonomics domain to improve the representation of anthropometric, biomechanical, and other physical characteristics. But other aspects of the classical human factors agenda for system engineering also warrant attention and now appear to be reachable. In addition to physical evaluation of human/machine design, capabilities are needed to—

- Allocate functions between people and machines
- Predict task performance times
- Evaluate task manning/crew size
- Minimize human error and its consequences
- Maximize safety
- Describe task steps and procedures
- Design jobs and job performance aids
- Develop training

- Forecast manning
- Select and assign personnel.[40]

Evaluation of these issues will surely benefit from accurate anthropometric and ergonomic models and data bases, but evaluation of the issues is not wholly subordinate to development of the models or dependent upon their perfection. Hence, a key issue for technology development is: To what extent might CAD, computer graphics human figure modeling, human performance information integration, and related technologies be exploited and combined to help evaluate a wider range of human-centered criteria during equipment design?

3. Data Base Integration and Knowledge Representation Technologies

Software interfaces allowing the workstation to interrogate external data bases relevant to maintenance task specification and analysis need to be integrated.

Data base integration and knowledge representation technologies are needed to better organize and synthesize human-centered information about task performance requirements and the task environment. The objective is to exploit existing knowledge and information about task performance requirements in human-centered analysis of new or modified systems. New media such as hypertext and compact disk/read-only memory (CD-ROM) will support the varied uses of human performance and human resources information needed in the HCT workstation environment.

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[40] Read the seminal work of Robert Miller, the landmark *Human Engineering Guide to Equipment Design*, and the Price et al. study of human factors contributions to system design and note the remarkable continuity in the human factors agenda through the decades.

R. B. Miller, *A Method for Man-Machine Task Analysis* (WADC-TR-53-137), American Institute for Research, Pittsburgh, 1953.

R. B. Miller, *Anticipating Tomorrow's Maintenance Job* (Research Review 53-1), Human Resources Research Center, Chanute Air Force Base, IL, 1953.

R. B. Miller, *A Suggested Guide to Position Structure* (ML-TM-56-13), Maintenance Laboratory, Air Force Personnel and Training Research Center, Lowry Air Force Base, CO, 1956.

H. Van Cott and R. Kincade, eds., *Human Engineering Guide to Equipment Design*, U.S. Government Printing Office, Washington, DC, 1972.

H. Price, M. Fiorello, J. Lowry, M. Smith, and J. Kidd, *The Contribution of Human Factors in Military System Development: Methodological Considerations* (TR-476), U.S. Army Research Institute for the Behavioral and Social Sciences, Alexandria, VA, 1980.

Potential data sources applicable to task specification, simulation, and performance evaluation include experimental literature, existing task analysis information, personnel and training data, field maintenance data, occupational safety and hazardous materials information, design guides and standards, and case history and lessons learned information.

There is a growing interest within many scientific disciplines relevant to human-centered design in discovering, systematizing, and representing their knowledge base. Examples of this phenomenon are found in the meta-analysis techniques used in the behavioral sciences.[41] Another example is Boff and Lincoln's compendium on human perception and performance for system designers.[42] Research in this area has two parts: identifying the state of scientific knowledge and other information applicable to a particular human-centered design issue and finding creative and effective ways of applying this knowledge and information to support the creation of improved human/machine simulation and design evaluation.

a. Automated Information Access

Human performance criteria contained in guides, handbooks, and military specifications and standards are being computerized in the hope of improving their usefulness in design and in other applications. The Army Human Engineering Laboratory, for example, has converted MIL-STD-1472, *Human Engineering Design Criteria for Military Systems, Equipment, and Facilities*, to hypertext format for use in a new microcomputer-based human factors analysis package.[43] Another example is the proposed

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41 J. Hunter, F. Schmidt, and G. Jackson, *Meta-Analysis: Cumulating Research Findings across Studies*, Sage Publications, Beverly Hills, CA, 1982.

M. Jones, R. Kennedy, J. Turnage, L. Kuntz, and S. Jones, *Meta-Analysis of Human Factors Engineering Studies Comparing Individual Differences, Practice Effects, and Equipment Design Variations* (SBIR Phase I Final Report, Contract F33615-85-C-0539), Essex Corporation, Orlando, FL, 1985.

42 K. Boff and J. Lincoln, eds., *Engineering Data Compendium on Human Perception and Performance*, 3 Volumes, H.G. Armstrong Aerospace Medical Research Laboratory, Human Engineering Division, Wright-Patterson Air Force Base, OH, no date.

43 Carlow Associates, *HFE/MANPRINT IDEA (Integrated Decision/Engineering Aid)*, for U.S. Army Human Engineering Laboratory, 1989.

conversion of the AFHRL Occupational Research Data Bank (ORDB), a key source of Air Force maintenance manpower, personnel, and training (MPT) data, to CD/ROM format. The Boff & Lincoln engineering compendium will also be converted for use in hypertext format on a Macintosh computer under the CASHE (Computer-Aided System Human Engineering) program.[44]

b. Maintenance Data Base Integration

A complementary movement within the MPT domain has focused on integrating the task descriptive information contained in the numerous Air Force data bases documenting maintenance work and equipment reliability and maintainability behavior. The most important and best known among these are the equipment maintenance records included in such systems as the Air Force Maintenance Data Collection System (MDC), and the occupational surveys conducted by the Air Force Occupational Measurement Squadron. Preliminary efforts to reconcile these data systems to support human resources analyses are documented in Driskill and Boyle.[45] The Defense Training and Performance Data Center (TPDC) is currently involved in similar work, called Crosswalk, to link equipment maintenance information with MPT information automatically. If these and similar efforts prove successful, the utility of the information in a human-modeling environment for maintenance will be greatly expanded. For example, the ability should exist to easily "benchmark" comparable maintenance tasks with human performance data such as overall task time, crew size, performing specialist, task difficulty, aptitude, and safety considerations.

4. Simulation Technology

Video simulation should permit examination of complete tasks so that their underlying ability requirements can be reliably inferred. Both physical and non-physical task requirements must be revealed to make better informed decisions about overall job design. Success in this would extend the uses of human-modeling technology beyond

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44 K. Boff, D. Monk, and W. Cody, draft, *Computer-Aided Systems Human Engineering (CASHE): a Hypermedia Tool*, RIAO 91 Intelligent Text and Image Handling, Barcelona, Spain, 1990.

45 W. Driskill and E. Boyle, *Task Identification and Evaluation System* (AFHRL-TP-86-xx), Air Force Human Resources Laboratory, Logistics and Human Factors Division, Wright-Paterson Air Force Base, OH, 1986.

anthropometric or biomechanical aspects of design evaluation to include cognitive performance requirements as well. Technology that is event driven, or object oriented will allow for the rapid development of realistic scenarios run as interactive, real-time simulations for testing design operability through the use of either actual human operators or simulated operators.

Rapid prototyping technology to develop soft prototypes of new systems for the evaluation of overt interface components and simulated system activity is advancing rapidly.[46] Human modeling tools will permit the concurrent engineering team to erect virtual or soft prototypes of human/machine and human/workplace interfaces using computer graphics workstations. Human performance process modeling technology developments will allow the evaluation of system operability through the emulation of normative human operators in the form of instantiated computational (artificial intelligence-based) human performance models.

Allowing human-in-the-loop simulation will provide the capability for human operators to operate the prototype system either as an individual or as a member of a team with modeled team mates. Human-in-the-loop simulation technology will allow the design to be analyzed by actual operational crews brought in to employ the systems in simulated missions. The concurrent engineering team can employ the representative scenarios to test the competing designs. The test results, along with the feedback from the operational crews, are interactively employed to improve the design until a design emerges that meets all performance parameters.

A new simulation technology that addresses human/system interaction is virtual reality, also known as "immersive simulation," telepresence," and "Cyberspace." Research in virtual reality evolved from 3-dimensional graphics and computer-aided design technology and is an interactive 3-dimensional form of computer graphics in which the user feels as though he is a part of the portrayed environment. Virtual reality requires at a minimum a computer workstation, a monitor, and special software. Movement through the environment occurs through movement of a joystick. An electronic or data glove may also

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[46] "A Technology Briefing on Rapid Prototyping," *CAD/CIM Alert*, monthly newsletter, 31 December 1990; "A Procedure for the Implementation of Rapid Prototyping," *SCAE Network*, Society for Computer-Aided Engineering, November 1991; "Changing Art into Metal," *SCAE Network*, December 1991.

be used with the headset to augment the sense of sight and allow users to manipulate objects in the environment and, ultimately, a data suit can be used to mimic the bodies movements on the monitor. Users can also become a part of the environment by wearing a stereo headset or goggles containing 2 small viewing screens that simulate a 3-dimensional image and change perspective as the user moves his head.[47]

Much research is taking place on this new technology in universities and computer companies, foremost among the latter those in the video-game business. Outside of the video game business, applications are being found in diverse fields such as architecture and air traffic control. Defense and aerospace companies as well as government laboratories or also investigating this new field for applications in training and design. The use of this new technology is still limited due to its high cost, poor graphics quality, and slow speed,; however, it is one that should be watched for potential applications in HCT.

5. User Interface Technology

Current human models would be greatly improved from a user's perspective if they provided more specific information and guidance about the known or projected advantages or disadvantages of particular human/machine designs. Often, the significant investment required to generate a computer graphic human model results in an impressive display but little practical guidance about the merits of a particular design from a human factors standpoint. Clearly, some way of aiding the design evaluation process once a display is created is needed. The issue involves engineering both the user-interface and the user-utility of human models. That is, it involves helping the user, and helping the user help the customer.

The software underlying human-modeling technology, which is graphics oriented, should present a graphics interface for design evaluation as well. The workstation user interface must be as modern as the human-modeling technology contained in the software. It is important for the success of human-centered design technology that people other than the computer programmers or software engineers who wrote the code be able to use the system to do useful task analysis work. There should be menus, windows, and other user-

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[47] "The Next Best Thing to Being There: An Exploration of Virtual Reality," *ASEE Prism*, May 1992. Ken Yamada, "Almost Like Being There," *The Wall Street Journal*, 6 April 1992.

oriented software tools that would allow the human factors analyst to expend more effort on his or her own craft and less on someone else's. In short, the human factors workstation should be carefully human factored itself. Leading edge work is focusing on natural language interfaces to make these models easier to use.

C. TAXONOMIC FRAMEWORK

In addition to their demands for physical strength and size, maintenance and operator tasks call upon a number of perceptual and psychomotor (or, simply, motor) abilities or skills. These include manual dexterity, multi-limb coordination, and color perception, to name a few. An important technology challenge will be to create task representations rich enough to allow an analyst to make reliable and valid inferences about the requirements for these and other relevant human abilities in proposed human/machine designs. To do this, a standard language for describing these abilities, or taxonomy, must be developed. In addition, how, and how well, these abilities can be represented and evaluated with available and near-term technologies must be evaluated.

A number of scientific approaches to this problem have been described. The best recent summary of competing viewpoints is probably that of Fleishman and Quaintance.[48] To take one example, Fleishman describes 52 distinct human abilities that appear to underlie performance differences in a wide variety of laboratory studies and that seem to have adequate psychometric standing. His taxonomy includes, in addition to perceptual, motor, and cognitive abilities, several strength and flexibility abilities that seem highly compatible with current human-model uses and capabilities. These latter are named static strength, explosive strength, dynamic strength, trunk strength, extent flexibility, and dynamic flexibility. Fleishman bases his taxonomic framework on what he calls an "ability requirements" approach. That is, his 52 human abilities are considered to be relatively enduring characteristics of people rather than trained skills.

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[48] E. Fleishman and Quaintance, *Taxonomies of Human Performance: The Description of Human Tasks*, Academic Press, Orlando, FL, 1984.

Another approach that may be applicable is the "task characteristics" method, also described in Fleishman and Quaintance and in Fleishman.[49] In this approach, attention falls on task-intrinsic properties. That is, they are independent of the human abilities they evoke. A task is conceived as having components: a goal, procedures, input stimuli, responses, and stimulus-response relationships. Each of these is decomposed into a number of task characteristics (e.g., precision and rate of response, number of procedural steps, and procedural complexity). A rigorous task descriptive language independent of the human operator is thus created. A third approach, called "job requirements matrix," attempts to link the ability requirements and task characteristics approaches.

The relevance of this psychometric research on human ability taxonomies is in establishing a scientific basis and a common framework for describing task requirements. Note that some of these taxonomies include, but go well beyond physical and ergonomic criteria currently evaluated by, the human models. There is no apparent reason why such ability taxonomies and task analysis methods rooted in the behavioral sciences could not be adapted to a new task analysis context based on human figure simulation. Task visualization provided by computer-graphics video simulation would be used instead of real-world performance measurement or written task rating scales as the basis for design evaluation of task requirements and for the instrumentation of task simulation techniques. The right taxonomic framework can also provide a task-level basis for eventually uniting the physical human factors with the "higher human factors" involved in MPT evaluation.[50]

It is difficult to specify in advance the exact arrangement and allocation of task descriptive information to visual vs. non-visual modalities and to animated vs. static displays. These depend on the rate of advancements in enabling computer hardware and software technologies and on the success of efforts to automate and apply relevant task performance knowledge and information for workstation use. Promising research in the critical technology of human figure animation is ongoing. The work of Badler and his associates at the University of Pennsylvania on the Jack model is noteworthy. (See Badler;

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49 E. Fleishman, "Toward a Taxonomy of Human Performance," *American Psychologist*, December 1975, pp. 1127-1149.

50 Task analysis is fundamental to all MANPRINT domains, but the disconnects in task data requirements and uses preclude a fully unified and efficient approach to HCT for design.

Badler, Lee, Phillips & Otani; Phillips & Badler; and Badler, Barsky & Zelzer.[51]) Jack is evolving into a general purpose task simulation and analysis tool with many of the features necessary for physical and psychomotor performance evaluation required by this research.

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51 Norman Badler, "Human Figure Animation," *Proceedings, National Computer Graphics Association*, Philadelphia, PA, 1989.

Norman Badler, P. Lee, C. Phillips, and E. Otani, "The JACK Interactive Human Model," First Annual Symposium on Mechanical Design in a Concurrent Engineering Environment, University of Iowa (Iowa City), October 1989.

C. Phillips and N. Badler, "JACK: A Tool Kit for Manipulating Articulated Figures," *Proceedings of the ACM SIGGRAPH Symposium on User Interface Software*, October 1988.

Norman Badler, Brian Barsky, and David Zelzer, eds., *Making Them Move: Mechanics, Control, and Animation of Articulated Figures*, Morgan-Kaufmann, San Mateo, CA, 1990.

VII. ENABLING KNOWLEDGE AND TECHNOLOGY FOR GROUP SUPPORT SYSTEMS

A. PAST, PRESENT, AND FUTURE DEVELOPMENT OF GST

The development of Group Support Technology (GST) may be characterized around three issues: the people motivating the development of the technologies, the areas of technology upon which developers concentrate, and the users or customers of the final products.

1. Drivers of GST Development

In the past, the designers of individual group support technologies (in particular the hardware), rather than the potential users, have driven GST development. Kraemer and King[1] call this the *engineering approach* to GST development. This engineering approach to GST development is *supply driven*, as designers (suppliers) of GST develop individual technological aids that they think decision makers (their customers) want. This is in contrast to *demand driven* innovation in which suppliers create technologies to fill a customer's need. This situation may have come about because it is easier to design technological aids presumably for decision making than to discern exactly what decision making is—the customers themselves may have difficulty describing exactly what it is they require or need. In this era of Total Quality Management (TQM) and customer focus, any future development of GST by Acquisition Logistics R&D Activity must be customer driven if we are to avoid spending a lot of effort and money on technologies that may be feasible but not highly desirable.

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1 Kenneth L. Kraemer and John L. King, *Computer-Based Systems for Cooperative Work and Group Decisionmaking: Status of Use and Problems in Development*, Public Policy Research Organization, University of California, Irvine, September 1986. (Hereinafter referred to as *Computer-Based Systems*.)

2. Technological Emphasis of GST Development

Kraemer and King identify two major streams in GDSS development: the study of human decision making and small group interaction, or *cognitive science stream*, and the development of technologically advanced hardware and software, or *engineering stream*. The engineering stream focuses upon the technical capabilities of the system, while the cognitive science stream focuses upon the system user. GST applications generally follow one development stream or the other, with more applications currently being developed in the engineering stream rather than the cognitive science stream. The strengths of the Acquisition Logistics R&D Activity may enable it to balance the streams. The technological emphasis of various types of GSS are described as follows.

Electronic boardrooms and *teleconferencing facilities* have generally followed the engineering stream in that they employ technologies to collect and tally votes quickly, share information through video displays, communicate over distances between meeting participants, and so forth. The use of these systems, which are generally passive, transmitting and displaying information as directed by the users, usually is not tied closely to the decision-making process itself.

Local area group nets and information centers have also generally followed the engineering stream, but with more consideration of the users of the systems. They employ "refined interfaces and non-procedural languages" to translate high level commands into system commands so the user can easily make requests of the system. These systems also are not directly involved in the decision-making process, but they do handle interaction between individual group members and provide data bases for the group to use.

Decision conferences and *collaboration laboratories* have tried to follow both the engineering and cognitive science streams. Designers develop technologies to facilitate acquisition and sharing of information. They consider cognitive science in the shaping of technologies into actual systems. Decision analysis, intelligent programming, and modeling systems enable users to perform "what if?" analyses and to prioritize objectives. These systems embrace cognitive science in theory, but even they lean more heavily on engineering technology because it is currently more mature than cognitive science technology.

The dominance of the engineering approach to GST development has a significant implication: In some cases a technology influences the decision process itself. Some applications of GST, like electronic boardrooms and teleconferencing facilities, mostly aid

communication or information presentation and do not affect the decision process. Other applications, like decision conferences and collaborative laboratories, are intended to increase the effectiveness of the decision process and can affect it significantly. Those types of GSS start with the system developer's views on the decision-making process. If the system developer's view is different from that of the group members the GSS is being designed to support, the decision making may take a different direction than it would without GST. This situation could adversely effect the quality of the decision making if the group members were uncomfortable with that predefined direction.[2]

3. Customers of GST

Traditionally, managers and executive decision makers have been the primary customers of GST and users of the various types of Group Support Systems (GSS). The Acquisition Logistics R&D activity seems to be in an excellent position to aid the managers and executive decision makers of the new Air Force Materiel Command (AFMC) with GST developed for their use in meetings and reviews or for the TQM process. The engineers, however, involved in the Integrated Weapon System Management (IWSM) process, including the practice of IPD or concurrent engineering, will most likely require vastly more complicated GSS than that required for managers and executive decision makers. Teams of many people associated with different engineering design, manufacturing, and support functions across the life cycle of the weapon system must work together *throughout* the product development process—not just during meetings or reviews. Especially with complex weapon systems, such as large aerospace vehicles, these teams and their members may be separated geographically in many companies across the nation or even the world. Many multi-company product development teams are already using teleconferencing, a type of GSS, to facilitate their decision making and cut down on the travel expense; but teleconferencing alone cannot support the information requirements of the whole product development process. Even when concurrent engineering team members are all located in one facility, effective meetings, reviews, and daily decisions will require extensive textual and graphical information from data bases or knowledge bases and fully validated models and simulations to study alternative designs and make decisions. The following section details the enabling knowledge and technologies that will be needed by the expanded customer base for GST.

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2 ibid.

B. ENABLING KNOWLEDGE AND TECHNOLOGIES

GST can refer to many different technologies and areas of knowledge. Advancements in one or more of them will make the corresponding GSS more effective. Thus they may be described collectively as enabling knowledge and technologies. In order that limited research and development resources can be allocated most efficiently, the areas of R&D that would potentially lead to the best GST products must be identified. This section breaks GST down into individual enabling areas of knowledge and technologies, describes their importance to applications and their current limitations, and identifies promising directions for future research.

1. Formal Methods and Technologies

Total Quality Management (TQM) includes a scientific approach to problem solving as one of its basic tenets. The scientific approach to problem solving is a systematic way to understand, learn about, and improve processes. The approach entails sophisticated statistical and experimental methods as well as some basic techniques for planning and tracking the processes. These formal methods and techniques emphasize graphics to assist the team in the visualization of the process. Since TQM involves problem solving by empowered teams of people, the formal methods used in TQM can be considered group support problem solving tools. These include, but are not limited to, the following:

- Quality Function Deployment
- Robust Design
- Fault Tree Analysis
- Affinity Diagrams
- Pareto Diagrams
- Cause-and Effect Diagrams
- Design of Experiments
- Failure Modes and Effects Analysis

Most of these formal methods were developed for a manufacturing organization. Although used extensively today by concurrent engineering teams, there may be some formal methods more applicable to the definition phases of product development. Although Quality Function Deployment (QFD) is applicable to the Requirements Definition phase,

most of the formal methods are statistical in nature and require hard data that is not available in the early stages of product development.

Currently, most of the formal methods are manual methods. The software that has been developed has not been developed to be used by a group in a team setting. The methods have been automated without concern for how a group of people may be able to use it. Opportunities exist in this area for the Acquisition Logistics R&D Activity to develop group user interface requirements for formal methods.

2. Communications Technology

Communications technology is central to most applications of GST and particularly to a Group Support System. A GSS involves moving information—from a computer to a projection screen, from one group member to another, from a data base to a workstation, or from one meeting room to a second one miles away. When Nunamaker and Vogel surveyed a number of different electronic meeting systems (EMS) to recommend how military organizations might use them most effectively, they determined that the objective of an EMS was to—

> provide seamless integration between the various [meeting] environments such that a group can more closely 'have it their way' in terms of the appropriate time and place to hold a meeting that may be independent of geographic and temporal constraints imposed on the group membership without losing face-to-face meeting effectiveness.[3]

Clearly, communications are a key to achieving this objective. In addition, communications technology is central to computer support for concurrent engineering. The CALS/CE ISG Frameworks report[4] identifies the following key communications requirements for concurrent engineering:

- Wide Bandwidth
- Multi-media—voice, audiovisual, graphic, and textual media
- Extensible Network to incorporate changing team members, location, and devices.

3 Jay F. Nunamaker and Douglas R. Vogel, *Application of Electronic Meeting Systems to Military Organizations*, ASQBG-A-89-031, U.S. Army Institute for Research in Management Information, Communications, and Computer Sciences (AIRMICS), June 1989.

4 CALS/CE Industry Steering Group (ISG), *Framework for Concurrent Engineering*, 1991, p. 24.

The next subsections discuss local and remote communications, respectively, including the above requirements. Local encompasses all communications within a single geographic location (i.e., within a single building) and enables use of a GSS for face-to-face meetings. Remote encompasses all other communications and enables use of a GSS for geographically distributed meetings.

a. Local

Local communications move information between hardware or software applications within a single geographic location. Some sort of local communication network will always be required to link applications, including those for Human Centered Technology (HCT) and GST. Local communication technology is truly "enabling" when it is sufficiently advanced to allow a team to transmit and receive information freely without adversely influencing the decision process or problem solving by itself. If it is not sufficiently advanced, it acts as a bottleneck, restricting the flow of information and reducing the effectiveness of the team and a GSS.

Some elements of a GSS, such as workstations for individuals and electronic blackboards or video screens for groups, will always be separated. In single-room meetings, it is often difficult to locate all of the computer support in the same room. Microcomputers, which are physically small and conducive to collocation, cannot now support all of the data bases and other software that may be needed in a GSS. It is usually necessary to link terminals in a decision room to a computer system elsewhere. If the local communications capabilities are not sufficient, the speed and reliability of a system can be adversely affected.[5]

Slow communication interferes with group interaction and progress. Concurrent engineering teams must be able to do analyses quickly and have almost instant access to the data the analyst needs. Fortunately, not every member on the concurrent engineering team needs access to every bit of information (e.g., the electrical circuit detail is not important to the mechanical engineers). Although the design data may be stored in a central data base, specific applications require only a portion of the total data. Still, the data transmission

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5 Kraemer and King, *Computer-Based Systems.*

speed is critical. Local communications using fiber optics with communications speed of 100 megabits per second (MBPS) are hindered when the bottleneck is the 30 MBPS computers.[6]

During a meeting each computer screen in a GSS has to be updated quickly enough to keep up with the discussion. Applegate et al.[7] evaluated three types of networks for an electronic brainstorming system: a baseband twisted-wire pair network with a strong server concept, a broadband coaxial cable network with a weak server concept, and an improved file structure and directory tree structure with a broadband network. Each new network was an improvement over the previous one, but group members still spent an average of 12 percent of their time in the work sessions waiting for a new screen. The average waiting time was 30 seconds per screen, but in times of peak loads, the waiting time per screen was as long as 2 minutes. After the work sessions group members commented that they sometimes lost ideas while waiting for new screens. Jarvenpaa et al. also found that a delay between the sending of an electronic message and its appearance on the screen tends to disrupt the meeting.[8]

Advances in computer speed and communications technology such as fiber optics should alleviate problems caused by slow communications. The hardware capability for GST is advancing rapidly, and enhanced capabilities appear to be almost "on the shelf" awaiting future application. In fact, hardware vendors may delay the release of a more capable technology until they feel pressured to do so by competitors, because the software market is slower in development and requires more time to exploit current hardware capabilities.[9] Private industry, fueled by healthy competition, appears to be making rapid progress in developing local network technology and computer hardware, and it appears that this technology will outpace development of other GST.

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6 See Chapter IV.

7 Lynda M. Applegate et al., "A Group Decision Support System for Idea Generation and Issue Analysis in Organization Planning," *Proceedings of the Conference on Computer-Supported Cooperative Work*, Austin, TX, 1986.

8 Sirkka L. Jarvenpaa et al., "Computer Support for Meetings of Groups Working on Unstructured Problems: A Field Experiment," *MIS Quarterly*, December 1988, pp. 645-666.

9 William Mansfield, Jr., Mid-Atlantic District Sales Manager, Cadence Design Systems, Inc., personal communication, CALS & CE Washington '91, Conference and Exposition, Washington, DC, June 1991.

b. Remote

Remote communications include all communication between geographically separate locations and that which supports distributed meetings. Remote communications may transmit the same information as local communications, but for distributed, multi-enterprise concurrent engineering meetings and GSS, audio and video signals become as important as data and text transmission. Concurrent engineering team members on a multi-enterprise project need to have the same type of "multimedia" capability available on all sites as well as the ability to share software applications and data. Provisions of extra channels or modes of communication in a GSS will increase the effectiveness and efficiency of the information transfer only if the users can manage the extra channels.[10]

Current remote communications technology supports teleconferencing with audio and video transmissions, electronic mail with text transmission, and remote computers with electronic data transmission. However, communications that are missing one or more media tend to be less as effective than face-to-face meetings. Comparison surveys between GDSS (in one room) and computer conferencing with only text transmission [local area decision nets (LADN)] suggest that LADN users "generate decisions of equal quality, are less likely to reach consensus, take longer to reach a group decision, are more likely to participate equally, and are more likely to engage in non-task behavior . . ."[11]

Still, it is easier to communicate face-to-face than over a computer terminal. Speaking is easier than typing and humans rely on vision more than any other sense—non-verbal communication (body language) is not possible without it. Voice and body language are often more effective means of communication between people than just text or even graphics. Researchers have observed that participants in face-to-face meetings tend to talk loudly rather than use their electronic notepads when discussions become heated.[12] Face-to-face transactions tend to hold one's attention better than remote data sharing, as the loss of communication media reduces the amount of information transmitted between the communicating parties.

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[10] Ease of use and cognitive overload have to be considerations in the development of GSS. These are discussed in Section B.3.a.

[11] Alan R. Dennis et al., "Information Technology to Support Electronic Meetings," *MIS Quarterly*, December 1988, pp. 591-624.

[12] Jarvenpaa et al., "Computer Support for Meetings."

In 1987, Detmar Straub and Renee Beauclair[13] published the results of a survey of firms conducted to investigate the use of GDSS. Three types of GDSS were considered:

- *Interfaced Conference or Computer Conference*—non-face-to-face conferencing via the computer at remote and/or local sites, e.g., electronic mail used for group decisions.
- *Face-to-Face Conference or Decision Room*—conference rooms with terminals or nodes for participants in group decision.
- *Face-to-Face Teleconference*—conference rooms at remote sites with video and telecommunications links, extended decision room.

Of these three different types of GDSS, face-to-face teleconferencing systems were the least used (fewer than three percent of the firms); respondents said that the systems were too costly and difficult to implement.

Research in GSS for concurrent engineering is being conducted at the Concurre Engineering Research Center (CERC). Researchers are developing the multimedia conferencing system, Meeting On the Net (MONET), for collocating people and programs.[14] The goal of this research, sponsored by the Defense Advanced Research Projects Agency (DARPA) through the DARPA Initiative in Concurrent Engineering (DICE), is to develop computer support for cooperative work that emulates a face-to-face environment and replaces desktop conferencing. It relies on asynchronous communications for electronic mail and file transfer.

Concurrent engineering for multi-enterprise development projects requires that one person be able to work with another miles away as though they were both sitting at the same desk. Engineering work, however, requires graphics and graphics transmission that with the current transmission rates is extremely slow or expensive. Today the individual technologies exist to allow multimedia communication between remote sites, but they generally have to rely on telephone line transmission (where the bandwidth is physically limited by the copper wire) or satellite transmission (which provides the wider bandwidth necessary for carrying much information, but is very costly).

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[13] Detmar W. Straub, Jr. and Renee Beauclair, "A New Dimension to Decision Support: Organizational Planning Made Easy with GDSS," *Data Management*, July 1987, pp. 11-12, 20.

[14] K. Srinivas et al., "MONET: A Multimedia Conferencing System for Colocating People and Programs," CALS & CE Washington '91, Conference and Exposition, Washington, DC, June 1991.

The development of the Integrated Services Digital Network (ISDN) should alleviate some of the problems with remote communications. The MONET researchers at the CERC are investigating the use of ISDN for real-time video transmission. The alternative is advancing the technology in video compression and data compression for transmission over existing networks. Myron Krueger, "the father of artificial reality" is also investigating ISDN.[15] He is developing a VideoPlace environment that uses computer-linked video cameras to convey images of remote users. Images of the remote users can be superimposed so they can point to data on the computer screen as if they were in the room. This technology does not impose the need to wear data gloves or suits. Researchers at Xerox Palo Alto Research Center (PARC) and Microelectronics Computer Center (MCC) are also investigating the use of artificial reality for remote communications.

3. Group Support Systems

Although single tools may be developed using HCT and GST, to function in an concurrent engineering environment they must be integrated with other tools into a computer system that provides many capabilities to its users. Since this computer system must support the concurrent engineering team, it is convenient to think of it as a group support system (GSS). The GSS that is developed for concurrent engineering must be integrated with other organizational information systems so that it is useful on a day-to-day basis and not just a curiosity that is impressive to demonstrate but rarely used.[16]

> Particular attention should be given to seamless integration between multiple session support methods and other organizational information functions (e.g., teleconferencing, computer conferencing, scheduling and e-mail). These are the types of things a focus on [Electronic Meeting Systems] EMS makes possible. The methods increasingly support "decision rooms without walls" in which organizational members can be participating in group sessions without the need to be continuously present in a single room.[17]

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15 Amy Bermar, "Network Innovators: Myron Krueger (Father of Artificial Reality)," Network World, Volume 8, Number 5, 4 February 1991, p. 51.

16 Jay F. Nunamaker et al., "Interaction of Task and Technology to Support Large Groups," *Decision Support Systems*, Volume 5 Number 2, North-Holland, June 1989, pp. 139-152.

17 Dennis et al., "Information Technology to Support Meetings."

In addition, this GSS must have an infrastructure that connects people and systems not only within a company, but also across enterprises. The GSS for a multi-enterprise concurrent engineering team must be capable of handling both spatial and temporal distances between team members.

Not only must this computer system be capable of supporting a geographically distributed concurrent engineering team, the team and groups in general will want their members to have the capability of working on different application programs at different times or working on the same program at the same time (sharing). This capability would be facilitated if software programs could run on more than one computer or workstation and if the programs could readily use data from another program transparently (the user does not have to type it in; it is transferred electronically). Ideally teams would be provided a tool box of application programs from which individual team members could choose the tools they needed at a particular moment.

Tools, standards, and a framework will be required to accomplish this. Two aspects to forming such a hardware and software system include:

- *System integration*—electronically linking the hardware and software so different people can use them at the same or different places and times.
- *System architecture*—arranging application programs in a framework in which they are most effective so a group or an individual can select those particular applications that best meet their needs.

a. System Integration

A GSS for concurrent engineering as it is envisioned in the future will include numerous applications programs, many of which may require data from each other. An engineer may want to generate some data with a model, retrieve more data from a data base, analyze the data on a spreadsheet, and display the results at a meeting using a graphics package. All of the relevant hardware and software must be able to communicate and share data for this to happen efficiently and effectively. Currently the process requires retyping data output from one program/machine to become data input for another.

Today there are generally two ways to make software and hardware compatible. One way is for the suppliers to adopt standards for product data and interfaces. In that vein, the CALS initiative supports the standardization of hardware and software. Emerging standards for product definition and information exchange include Manufacturing

Application Protocol (MAP), Technical Office Protocol (TOP), Initial Graphics Exchange Standard (IGES), Electronic Design Interchange Format (EDIF), UNIX operating system, Electronic Data Interchange (EDI), and Product Data Exchange Standard (PDES).[18]

The other way to enhance the compatibility of software and hardware is to develop translators that are added to existing software packages or pieces of hardware to make them compatible. The data is then translated and reformatted between computer programs. Researchers at the Concurrent Engineering Research Center (CERC) in Morgantown, West Virginia, are developing "wrappers" to attach to heretofore incompatible software packages, enabling them to be arranged within a single framework.[19] The framework forms a tool box from which people can select tools as desired without having to change to a different computer network or a different user system.[20]

b. System Architecture

System architecture is the design of the tool box from which group members can select and use the applications programs, which must support a wide variety of tasks. An open modular system architecture is required to allow hardware and software to be plugged into the framework and swapped out as needed. The architecture must support the use of a shared data base that can be accessed by one or more programs at the same time and provide multiple views of the design so each user can obtain the view they need.

One of the emerging technologies that will provide the concurrent engineering team with a distributed system composed of data bases and applications programs, is the Client/Server architecture. This is a system in which "the client is used for local applications processing and primary user access, and the server is used to retrieve data

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18 Jacky C. Prucz (WVA/CERC), "Phased Implementation of Concurrent Engineering (CE)—Key to Overcoming Cultural, Financial and Technical Barriers," *Proceedings of the CALS&CE Washington '91 Conference & Exposition*, Featuring the Third National Symposium on Concurrent Engineering, 10-14 June 1991.

Additional standards were discussed in Chapter IV.

19 J.W. Lewis and the DICE Team,"Wrappers Integration Utilities and Services for the DICE Architecture," *Proceedings of the CALS&CE Washington '91 Conference & Exposition*, Featuring the Third National Symposium on Concurrent Engineering, 10-14 June 1991.

20 Frameworks were discussed in detail in Chapter IV.

from the appropriate location, access the appropriate analysis tools as required, and return the results to the client."[21]

More planning for formal team meetings may be required when a GSS is used to analyze and support decisions than when it is not. Decision support may involve the use of models or decision conferencing software such as uncertainty, tradeoff, and preference analyses packages. When these technologies are used, it is important to set up the agenda of the meeting and to ensure that the group uses the best tools for the problem at hand.[22] The GSS architecture should facilitate this—perhaps a library of elements of problem-structuring methods can be collected so that a team can easily choose the ones most appropriate to the particular problem at hand and the team's particular style.[23] In addition to providing tools for team members to use during the meeting, the system architecture should help meetings move smoothly by supporting meeting agendas and should provide tools for the meeting facilitator (if one is present) to use during the meeting.[24]

Given the importance of matching the tools to the problem, Wood suggests the following systems and cybernetic concepts and principles for inclusion in a group decision support system architecture [Deutsch, *Nerves of Government* (1963) and Beer, *Decision and Control* (1966) and *Brain of the Firm* (1972)]:[25]

- *Functional diagrams of information flow*, used to match decision support tools to the real-world environment regarding which decisions are to be made.
- *Requisite variety*, matching the complexity of the decision support system to the real environment.
- *Coenetic variables*, determinants of the real-world situation and disturbances of it.

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21 Robert M. Beggs and Julius M. Etzl (Boeing Defense & Space Group, Helicopter Division), "Beyond Design Build Teams—Computer Based Concurrent Engineering, *Proceedings of the CALS&CE Washington '91 Conference & Exposition*, Featuring the Third National Symposium on Concurrent Engineering, 10-14 June 1991.

22 Dennis et al., "Information Technology to Support Meetings."

23 Patrick Humphreys and Ayleen Wisudha, *Methods and Tools for Structuring and Analyzing Decision Problems*, Decision Analysis Unit, London School of Economics and Political Science, Technical Report 87-1, Volume 1: A Review, 1987.

24 Joey F. George et al., "Group Decision Support Systems and Their Implications for Designers and Managers: The Arizona Experience," *DSS-88 Transactions*, Boston, 1988.

25 Fred B. Wood, "Advanced Systems for Program Appraisal: Prospects for General Systems Decision Support Centres in the USA," *Project Appraisal*, Volume 2, Number 2, June 1987, pp. 73-140.

- *Conceptual and homomorphic models*, the identification and verification of variables and relationships that logically and literally describe the real world.
- *Feedback analysis*, where the group support system models variables and identifies values that amplify or dampen deviations from a given norm or objective
- *Self-organization*, where the decision support package monitors the couplings among action options and key variables external and internal to a model.
- *Algedonic loops*, fail-safe devices that warn decision makers when values of certain variables in a model reach critical levels.

Most of these functions support decision modeling in areas like business or psychology that do not already have a set of well-understood principles and laws like science or engineering. Concurrent engineering teams may have to construct their own models to match the specific situation about which they are making decisions. Since these modeling aids are essentially in their infancy, there is much work that could be done to improve them. A goal would be to produce a system architecture in which team members, who may not be experts in modeling and decision conferencing tools, could use them without external assistance or instruction.

4. Information Presentation

Information presentation technology is similar to human/computer interface technology (see Section 5) in that it encompasses hardware and software involved in transmitting information between humans and computers, but it emphasizes GSS capability or performance (e.g., the amount or type of information a system can present) rather than the ease of use or ease of learning of the system.

Information presentation hardware and software go hand in hand and are important to the overall performance of a GSS. Information presentation hardware includes a large number of devices used to present information such as electronic blackboards, large video screens, workstations, projectors, loudspeakers, etc. Software includes that which controls the hardware. It may allow, for example, a workstation user to display data on different types of graphs. Technologies such as multiple screen projectors, audio and video recorders, optical disks, and electronic blackboards all increase the performance of a GSS facility.[26]

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[26] George et al., "Group Decision Support Systems."

Researchers of GST have identified limitations of information presentation technology in the areas of display technology, graphics technology, and multimedia information presentation. Discussions of the state of the art in this area quickly become obsolete, however, as industry rapidly pushes new and ever more capable equipment onto the market.

a. Display Technology

Most video projectors are not designed to operate in conjunction with computer displays, especially with high resolution graphics. Screen resolution is essential to the use of high quality graphics—quality graphics make screens easier to read and make presentations more effective. Both the public or large screen presentation and workstation presentation are important to the quality of a meeting. High resolution video projectors are very expensive. The price of projectors will come down as technology advances, but group support systems will have to be seen as very important tools or used very often for such an investment to be worthwhile.[27]

Electronic blackboards appear to be more flexible than flip charts, but the electronic blackboards would be even more powerful if the memory of the computer were used to greater advantage. The ability to recall previous slides or to produce backup slides would be useful. The blackboard and supporting computer could also be set up to display information from disks or other external sources, such as a computer network.[28] The rapid advance of information presentation technology should make both of these areas of technology more attractive in the near future.

b. Graphics Capability

A GSS must be able to display the results of analyses quickly and effectively. In spite of the continuing advance of technology, it is particularly difficult to rapidly and automatically turn computer-generated data into high quality graphic displays. In addition, it is difficult to display more than one portion of the data at one time. The amount of relevant data can easily overload the capabilities of the screen or the video projector.[29]

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27 Kraemer and King, *Computer-Based Systems.*

28 Jarvenpaa et al., "Computer Support for Meetings."

29 Kraemer and King.

Again the advance of computer hardware technology and the ever-improving graphics workstations should mitigate these problems, if they can be made affordable.

c. Multimedia Information Presentation

A workstation must allow group members to display data in a number of different forms concurrently. Multimedia presentation is more powerful than text or video images alone. A small computer screen, for example, makes it more difficult to group and rank ideas generated by brainstorming. Applegate et al. believe that it is very important for group members to have a "world view" of the results of brainstorming not limited by the size of a computer screen.[30] In experiments conducted by Applegate et al., users spent a lot of time (27 percent) just reading the comments of other group members. Users indicated that typing and reading were less efficient means of communicating than speaking and listening.

Gray and Olfman[31] also believe that a user should be able to pull up and edit material on the main screen or a personal screen. Individual workstations should be able to display information in multiple languages different from the one used on the main screen (this would be especially important for remote meetings or teleconferences). Participants should be able to tailor their screens so they can best understand displayed information (e.g., use bar graphs or pie charts instead of lists of figures).

5. Human/Computer Interface Technology

The human/computer interface is one of the most critical issues in the development of GST. Since all information passes through it, a GSS can only be as effective as its human/computer interface. This issue encompasses everything related to the transfer of information between a human and a computer—

- The way a human transmits information such as through a keyboard, a mouse, digital-video interaction, voice activation, or high-level computer languages.
- The way a system presents information such as through audio speakers or video screens.

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30 Applegate et al., "A Group Decision Support System."

31 Paul Gray and Lorne Olfman, "The User Interface in Group Decision Support Systems," *Decision Support Systems*, Volume 5, Noumber 2, North-Holland, June 1989, pp. 119-137. (Hereinafter referred to as "The User Interface in Group Decision.")

- The training or familiarity required to use a GSS.
- The ease of use of a GSS.

This following discussion divides human/computer interface technology issues into two parts. The first, interface technology, encompasses all of the hardware related to human-machine communication (e.g., keyboards, mice, video screens, etc.). The second, high-level computer languages, encompasses software that allows group members to create computer models without being trained computer programmers.

a. Interface Technology

Observations of GSS use have confirmed the importance of human/computer interface technology. Nunamaker et al.[32] have done work with over 90 organizations using two GDSS facilities at the University of Arizona and have concluded the following regarding the interaction of people and technology in a GDSS:

- Software must be powerful and easily used to satisfy participants.
- Group processes are fragile; a GDSS should not frustrate or impose upon users.
- Human-system interfaces should be flexible and allow for different levels of "keyboard literacy" and familiarity with the system among users.
- The user interface should use a combination of graphics, windows, overlays, help screens, and other features that "help group members feel that they are receiving a measure of professional respect and at the same time gives them confidence in the system's support capabilities."

The sources of problems with a GSS human/computer interface identified by researchers can be summarized as follows:

- *User unfamiliarity with computers.* Users who are unfamiliar with computers often have difficulty or are frustrated with a GSS.
- *Use of the computer keyboard.* Typing is less effective than either handwriting or speaking as a means of communication; not everyone types equally well.
- *Training required to use a GSS.* If extra training is required to use a GSS, senior decision makers may be deterred from doing so. Meetings may be less effective because partially trained group members are not comfortable with the system.

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32 Nunamaker et al., "Interaction of Task and Technology."

- *Information/work overload of GSS users.* Having to act upon too much information at once is difficult and frustrating. It draws the attention of the group away from decision making.
- *Loss of social contact between group members.* Group support systems that omit some communication media reduce social contact between group members, potentially reducing the effectiveness of a meeting.

User Familiarity. The assumed degree of computer familiarity attributed to the GSS user is an important aspect of GSS design. Many experiments have been done to measure the effectiveness of a GSS. Most of them used subjects who were not terribly familiar with computers, a factor which may have hampered the progress of meetings and reduced the satisfaction of the subjects. Those familiar with computers would not have had the same problems and presumably would have been happier with the GSS. Group members and meeting facilitators must be able to use equipment without excessive training or staff support if GST is to be adopted widely.[33]

There is real-life as well as experimental evidence that a user's acceptance of GSS correlates with his familiarity with the system and the ease with which he uses it. The Software Technology Program at the Microelectronics and Computer Technology Corporation has developed rIBIS (real-time Issue-Based Information System), a real time group hypertext system that allows multiple users to browse and edit multiple views of a hypertext network. Users of rIBIS have rated it from "frustrating and unproductive" to "satisfying and productive," typically as a function of their experience with the system. Developers of rIBIS have found that even small improvements to user friendliness can significantly affect the acceptance of the system as a useful tool.[34]

Keyboard Usage. User difficulties with the computer keyboard often go hand in hand with a lack of familiarity with computers. Most regular computer users have come to deal with the limitations inherent in the keyboard—the slowness and increased difficulty of transmitting information relative to speaking or writing. However, those limitations can be particularly frustrating to people who do not use a keyboard regularly. Applegate et al.[35] found that some executives using GST were good typists and were not frustrated by the keyboard, but some were very poor typists and were frustrated. They did not find that

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33 Jarvenpaa et al., "Computer Support for Meetings"; George et al., "Group Decision Support Systems."

34 Gail L. Rein and Clarence A. Ellis, *rIBIS: A Real-Time Group Hypertext System*, MCC Technical Report Number STP-095-90, March 1990.

35 Applegate et al., "A Group Decision Support System."

role conflict within the executives (belief that "executives should not have to type") hampered their use of the system; however, they did find that some executives were anxious about their skills with computers in general.

When Applegate et al. designed the Management Information Systems (MIS) Planning and Decision Laboratory (PDL), they were initially concerned about the need to type messages and commands on a keyboard. Previous work suggests that it is most effective to give a computer user the human/computer interface they most prefer. Executives would prefer a "desk-top" style interface—voice activation, light pens, and mice have been proposed as technologies to support it. Voice activation and transmission could eliminate the keyboard, but the problem with two or more people talking at once remains to be solved. Nunamaker et al. also suggest that research should be done to find user-friendly alternatives to keyboards and screens for group feedback to members' contributions. Gray and Olfman[36] also believe typing should be eliminated as much as possible.

Training. The training required to use a GST application can be a barrier to its use. Huseman and Miles[37] emphasize ease of use as being an important factor in their discussions of the effect of different computer-based systems upon organizational communication. When decision support systems are not easy to use, they are not easy to learn and will not be used. Users will not spend an inordinate amount of time and effort to become familiar with the system and the computer. The Executive Information System training session for new executives at Lockheed-Georgia takes 15 minutes, which is reasonable. The requirement for computer-specific skills has been eliminated in many successful GSS with mice, touch screens, and a few function keys replacing the keyboard and making them easier to learn. Designers of GST applications can make them attractive to users by employing technologies like color, overlays, windows, help screens, and tutorials. Embedded training in the system itself should be considered; this approach has been proposed in order to eliminate the need for a facilitator.[38]

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36 Paul Gray and Lorne Olfman, "The User Interface in Group Decision."

37 Richard C. Huseman and Edward W. Miles, "Organizational Communication in the Informational Age: Implications of Computer-Based Systems," *Journal of Management*, Volume 14, Number. 2, 1988.

38 Discussions at the Government Group Decision Technology Conference held at the Federal Executive Institute in Charlottesville, VA, 23-25 September 1991.

Information Overload. Both the human interface with individual GST applications and the human interface with the entire GSS must be considered. In particular the work load of the users of a GSS must not be so high that they have to concentrate more on assimilating all of the information they are receiving than on making decisions about the subject of the meeting. Jarvenpaa et al.[39] performed experiments comparing the effectiveness of networked workstations, electronic blackboards and notepads, and conventional pencil and paper. In those experiments the workstations were apparently difficult to use. Participants had to type on a keyboard to take notes, read their screens and watch the flip chart presentation in addition to talking to other participants. Participants complained that the work load kept them from listening and talking to each other.

Individual technologies must also be designed with work load in mind. An anonymous message system provided with the workstations in the above experiments was difficult to use—the messages were formatted such that it was difficult to put them in the context of the discussion and participants had to spend time creating messages rather than talking to each other. The participants made more "non-task related" remarks when using the workstations. Many of these remarks were questions about the current status of the meeting, suggesting that using the workstations interfered with the user's listening. The participants also spent time setting up guidelines to use the workstations for things like voting. These experiences demonstrate that the cognitive load on people using workstations must be kept to a manageable level.

Social Contact. The last issue related to the human computer interface is the effect of GSS upon the social contact between group members during a meeting. Social interaction is an important aspect of human communication, but the use of electronic media during a meeting can reduce the social cues and social interaction.[40] Meeting participants tend to look at their screens when they talk, reducing eye contact and social contact. Dead time is added to a meeting while participants type on their terminals or read their screens. Participants also tend to talk less when they are using GST. All of these factors could decrease the quality of the discussion and lower the group satisfaction, making consensus more difficult to achieve.

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39 Jarvenpaa et al., "Computer Support for Meetings."

40 ibid.

b. High-Level Computer Languages

High-level computer languages encompass software that allows group members to create computer models without being trained computer programmers. Groups may use the models to represent either some aspect of the subject of a meeting—in order to better understand it—or the decision process itself—in order to better understand their own thinking.

One reason why the methods and tools for analyzing decisions are not more widely used is that these methods and tools use models and languages that are too abstract and difficult for decision makers to understand. Another reason is that some of the methods and tools do not consider the decision maker's own preferences and judgment. A third reason is that some systems are not interactive or cooperative, so that the decision makers never get to communicate freely among themselves.[41] In addition, some decision analysis methods demand forms of participation that are inconvenient or uncomfortable for the participants.

Humphreys and Wisudha[42] found no decision support system that could "work with the decision maker's own problem structuring language in determining the bounds of a problem through scenario generation." They recommend researching the development of decision support systems in which decision makers can use their own problem structuring languages, e.g., free-form scenario development aids used to identify frames and options of problems. Language interpretation would be a facilitating technology. Researchers have developed frameworks for modeling man-machine interactions, and these suggest that it would be possible to develop a language "for information presentation and elicitation in the user-computer dialogue process."[43]

6. Cognitive Science Technology

A substantial barrier to the success of GST applications and the corresponding GSS arises due to an incomplete understanding of the human decision-making process. Decision models currently focus on the relatively narrow rational view of human decision making: Group members try to optimize their decisions based upon careful consideration of the situation and the consequences of alternative decisions. However, individuals often

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41 Humphreys and Wisudha, *Methods and Tools.*

42 ibid.

43 Nunamaker et al., "Interaction of Task and Technology."

exhibit irrational or quasi-rational behavior when making decisions, limiting the effectiveness of a GSS based upon a rational model. Unfortunately, as cognitive science is relatively young, the rational model of decision making is better understood than any other. It also provides clear-cut rules around which decision-making aids can be designed. Other, non-rational decision models are somewhat "fuzzy" with respect to decision behavior and thus are very difficult to use for designing decision-making aids.[44] Research into human decision making is needed to make GSS more effective, especially in decision settings that do not conform to the rational decision model.[45]

7. Knowledge and Data Bases

Computer data bases are fairly common today although most are operated independently rather than integrated with other GST into a GSS. However, knowledge and data bases can be very useful tools for group support. Groups can consult a data base anytime a question arises that requires more information to answer, so group members do not have to prepare and carry their sources of information either physically or mentally. Knowledge bases can act as an "organizational memory" from meeting to meeting. Meeting facilitator knowledge and expertise could even be embedded in a knowledge base and used with an on-line monitoring system to help groups use other applications of GST.[46]

Expert systems, a form of knowledge base, can act as supplemental group members by supplying the knowledge, in the form of data and principles, of a number of experts in a field. Expert systems can even aid in the training for and use of the GSS, "guid[ing] the selection of tools and respective output reports to best meet group needs and further act[ing] as a monitor and directing mechanism during [a meeting] to assist the facilitator."[47]

44 Kraemer and King, *Computer-Based Systems*.

45 The new technology known as fuzzy technology, resulting from fuzzy logic, can help decision makers with decisions in which uncertainty is present. This technology appears to be an enabling one for GST development and should be investigated, although no research at IDA has shown applications in this area at this time.

46 Nunamaker et al., "Interaction of Task and Technology."

47 George et al., "Group Decision Support Systems."

In spite of the availability of data bases and GST, many issues need to be addressed concerning their use to support group problem solving or decision making. Among these are the following:

- *Qualitative or "soft" information.* People are concerned about soft factors affecting decisions. Information on soft factors is often stored in the heads of experienced people, not in a data base, although computer expert systems are beginning to address qualitative information.[48]
- *Integrated data base/modeling capability.* Decision conferences and collaborative laboratories usually depend upon information supplied by group members that they collected outside of the meeting. It would be desirable to include a data base in a GSS so that groups could build models without having to identify and collect relevant data beforehand. This should be technically feasible but has not yet been done.[49]

A fully integrated GSS could address the latter problem if it contained a modeling capability and a related data base—something that is technically feasible today. If a knowledge base were integrated with a group communication system, group members could easily use information and analysis both internal and external to the meeting, either individually or cooperatively with other group members.[50]

There are several new optical technologies that may make significant contributions to the development of the IWSDB, particularly for the secure creation, storage, retrieval, and dissemination of vast amounts of digital data.[51] These technologies include—

- Compact Disk Read-Only Memory (CD-ROM)—allows for the storage and retrieval of about 600 megabytes of data.
- WORM—allows the user to write once to the CD.
- Re-writable CD—allows the user to write, erase, and re-write to the CD.

8. Modeling and Preference Technology

Groups use modeling and preference technology to help analyze problems about which they are making decisions. Modeling and preference tools are contained in a GSS to

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48 Lawrence Phillips, "Systems for Solutions," *Datamation Business*, April 1985, pp. 26, 28-29.

49 Kraemer and King, *Computer-Based Systems*.

50 George et al., "Group Decision Support Systems."

51 Matthew Leek, "The IWSDB and Optical Technology: What Role Does it Play?," presented at the CALS Expo '91, Conference & Exposition, Phoenix, AZ, 11-14 November 1991.

aid the decision making process.[52] Modeling and preference technology may be broken down into two parts: (1) model generation and management and (2) preference analysis. Model generation and management entails the creation of logical, rule-based models to evaluate scenarios or the consequences of decision options and the examination of the principles and assumptions supporting the models. Preference analysis is a means of clarifying the thinking of the decision makers themselves through the use of software like preference elicitation and uncertainty analysis.

a. Model Generation and Management

Model generation tools enable a group to build logical, rule-based models to compare scenarios coherently, use decision analytic techniques to develop pathways between immediate acts and subsequent consequences (create event trees), work backwards from consequence to initiating events (create fault trees) or negotiate while supporting stakeholder's views within a consistent frame of reference and capturing scenarios in terms of their equity with respect to all parties.[53] Modeling helps people to clarify their thinking and their preferences. The process usually goes through a number of iterations before the group making decisions agrees upon the model and the results it produces.[54]

Decision conferences and collaborative laboratories use models to help groups structure problems and grasp the meaning of raw data. Simpler modeling tools start from pre-existing conceptual models or structured knowledge bases. They include domain-specific expert systems, submodels to help predict consequences of decisions or analytic simulation methods for use within conceptual models in which information is described algebraically.[55] Spreadsheets are widely used, but more work is needed in the area of simulation and econometric analysis, which need much more powerful computer support and usually a skilled analyst to assist the group. It would be desirable to have more powerful software that a group could quickly and easily use by itself.[56]

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52 The term GDSS is used here because of the emphasis on decision support.

53 Humphreys and Wisudha, *Methods and Tools*. The creation of fault trees was seen as a needed capability by the GD Convair engineers as well.

54 Phillips, "Systems for Solutions."

55 Humphreys and Wisudha.

56 Kraemer and King, *Computer-Based Systems*.

Self-supporting models would be very valuable because they would not require the support of a developer or group of developers. Modeling is widely used within the scientific and engineering communities, but the developers of a model must often support its use with their first-hand knowledge of its creation. A self-supporting model could be distributed and used much more widely. The next step would be modeling tools that would allow decision makers without highly detailed knowledge of a subject to *create* models to scope out, perhaps roughly, the consequences of decisions.

Model management tools enable a group to examine the underlying principles and assumptions of models and to directly compare different models of the same phenomena.

> Model management is an important function of GDSS. Because of human cognitive limitations, people usually use models to help them understand, organize, study and solve problems. This is particularly true when the problem to be solved is complex and difficult. In this case, computer-based decision models may be crucial to the quality of the decision. . . . [it] would be very useful if GDSS provided functions that allowed the [group members] to examine what models were used to generate their [data], what assumptions were behind these models, and how these models were evaluated.[57]

Model management tools can help a group examine, manipulate, and develop decision models, and may support group modeling to different degrees. In their simplest form, they might display the results of models used by different individuals in the group. They might display a particular model and allow all of the group members to see how it works and to use it themselves. They might allow group members to change a model or to combine parts of different models to form a new model. In their most advanced form, model management tools would support group modeling intelligently, based upon the users' specifications. They would integrate parts of one or more models automatically or advise group members on model creation and selection. They would eliminate much of the trial and error involved in creating a model manually from a collection of parts or submodels.[58] Model management tools will be essential if decision makers are to use a large number of possibly quite different models.

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[57] Ting-Peng Liang, "Model Management for Group Decision Support," *MIS Quarterly*, December 1988, pp. 667-680.

[58] ibid.

b. Preference Analysis

Groups use preference analysis to help clarify their thinking. Preference analysis tools aid the user in judging the worth of opinions and consequences. They include tools based upon multi-attribute theory, heuristic rules, and semi-ordering methods.[59] Preference analysis packages elicit the user's true preferences by asking them questions about the choices to be made, the user's objectives, and the tradeoffs between those objectives. People can use preference technology to help make value judgments, form preferences, and make tradeoffs.[60]

In spite of the availability of computer-based decision support, many decision makers still rely upon purely subjective judgment. They watch the presentation of data on the computer but then turn away when it is time to act upon the data. This undoubtedly is because decision support does not yet satisfy the needs of the decision makers.[61] Under present technology, computers are best used as partners or extensions of the brain to help clarify one's thinking or show the implications of various decisions. Present (and perhaps future) limitations of the computer include the following:

- *Computer data bases only contain information about the past.* Humans decide about the future. Senior executives need to look 10 years or more into the future; data contained in a data base can help to support a decision, but people tend to rely upon subjective judgment.
- *Computers do not now assess uncertainty of events.* Judgment involves determination of the risk involved in course of action. Computers can, however, show the results of different scenarios based upon the various outcomes of uncertain events ("what if?" analyses).
- *Computers cannot specify tradeoffs between conflicting objectives.* People must consider multiple and sometimes conflicting objectives when making decisions. Computers cannot specify which objectives should be traded off against each other, although they can show the results of alternative tradeoffs if people program them to do so.
- *Computers cannot form preferences.* Forming preferences involves both assessing soft factors and ranking tradeoffs between conflicting objectives. People tend to rely upon subjective judgment when forming and weighing degrees of preferences.

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59 Humphreys and Wisudha, *Methods and Tools.*

60 Phillips, "Systems for Solutions."

61 ibid.

VIII. ALTERNATIVE R&D STRATEGIES

The sections in this chapter define broad strategies that derive primarily from customer needs and identify the strengths and weaknesses of each strategy with respect to the capabilities and location of the Acquisition Logistics R&D Activity. The general strategies are presented in order of decreasing importance with regard to Human Centered Technology (HCT) and Group Support Technology (GST) as judged by the various factors discussed. The introductory section gives overall strategies that we feel are important to the total Acquisition Logistics R&D Activity's goals.

A. OVERALL STRATEGIES

The overall strategy is more of a marketing strategy than an R&D strategy because it applies to all the HCT and GST activities of the Acquisition Logistics R&D Activity. This strategy is to promote these technologies as *process* technologies. *Product* technologies are those technologies that improve the performance of the end product (i.e., weapon system); process technologies are those technologies that provide for the efficient and effective introduction of the product technologies into the product (traditionally these are manufacturing process technologies). During our concurrent engineering research at IDA, it has become evident that concurrent engineering will not survive without process technologies as well as product technologies.[1]

HCT is technology that is applied to the human interface with operational, support, and manufacturing processes to make them more efficient, safe, and affordable. GST is technology that is applied to the processes of design, planning, and improvement to make them more efficient, effective, and affordable.

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1 Process technologies are an important part of the new Science and Technology Strategy of the Director, Defense Research and Engineering (DDR&E), and a primary element of Thrust 7 of that effort, Technology for Affordability. Dr. Robert White, president of the National Academy of Engineering, said in a seminar at IDA that process technologies were essential to the nation's competitiveness as well.

The other overall strategy is for the Acquisition Logistics R&D Activity to become an active participant in the Concurrent Engineering Research Center (CERC) in Morgantown, West Virginia. Opportunities here involve putting the HCT models[2] that are developed on the concurrent engineering research testbed. Although this testbed is still in a research environment, it is integrated and can provide a good test for the model. In addition, the model will get high exposure. GST developed for concurrent engineering use can also be tested in this environment. Interaction with the CERC, as with Industry-University Research Centers, provides a low-cost activity for the exchange of technical information and products between the Acquisition Logistics R&D Activity and the Centers.

B. HUMAN CENTERED TECHNOLOGY OPPORTUNITIES AND STRATEGIES

Human Centered Technology as envisioned by the Acquisition Logistics R&D Activity (computational human factors, integration with CAD, tools for designing for high reliability and ease of maintenance) should play an important role in the new acquisition strategy as emphasis shifts from production to R&D with and without prototyping.

> Computer-aided design, computer simulation of operational environments, a design philosophy emphasizing high reliability and ease of maintenance, and automated flexible manufacturing would all make this type of research a more practical alternative.[3]

1. Manufacturing Domain

Today there is probably no greater issue affecting U.S. global competitiveness than the health of the industrial base and, consequently, the defense production base. Because of the current concerns for maintaining a defense industrial base, we see an opportunity for the Acquisition Logistics R&D Activity to provide HCT for the manufacturing domain as well as for their traditional customers in the reliability, maintainability, and supportability (RM&S) domains.

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2 This opportunity exists not just for HCT or GST but for other concurrent engineering related tools, such as the Reliability and Maintainability in Computer-Aided Design (RAMCAD) system also developed by the lab.

3 U.S. Congress, Office of Technology Assessment, *Redesigning Defense: Planning the Transition to the Future U.S. Defense Industrial Base*, OTA-ISC-500, U.S. Government Printing Office, Washington, DC, July 1991. (Hereinafter referred to as *Redesigning Defense.*)

At the 1990 Autofact, a CAD/CIM exposition, new tools and capabilities that allow the consideration of manufacturing issues much earlier in design were demonstrated. Demonstrations showed technological advances in rapid prototyping, advanced visualization and animation as a prototyping alternative, data base integration, parametric design, and surface solids modeling. The following concern, however, was voiced by participants at the exposition:

> Investment in the workforce, both to provide an increasingly safer and more productive work environment and to provide the necessary levels of training and education for world class performance, will further drain capability for other competitiveness investments.[4]

In the current environment of manufacturing industry, problems are not so much with the development of manufacturing technology as with the ability to adopt this technology in industry. Many of the problems associated with the successful adoption of the technology are people problems—e.g., the required skill levels, the inadequate human-machine interface.

A key finding of a 1990 Coopers & Lybrand survey, "Made in America III: The Globalization of Manufacturing," was that manufacturers perceive that difficulties in hiring, training, and retraining skilled workers are a major obstacle to globalization.[5] American manufacturers are aware that the future skill requirements of their employees will be significantly greater than in the past. "Manufacturers are spending tremendous amounts of money and resources on education and training, but there is still concern that the skill level of all employees may not be competitive with the Japanese workforce."[6] Some of these problems are illustrated in the following statistics.[7]

- In general, U.S. manufacturing has adopted advanced production technologies at remarkably low rates—particularly as regards state-of-the-art equipment.
- In effect, it takes 55 years for 90 percent of U.S. manufacturers to adopt new technologies; in Japan, it takes only 18 years.

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4 "Industrial CALS: Capturing the Competitiveness Advantages," *SCAE Network*, September 1991.

5 "Coopers & Lybrand Survey: U.S. Manufacturers in the Global Market," *CAD/CIM Alert*, November 1990.

6 Remarks by Markus Clark, project manager, "Manufacturing Strategy and Planning, Technical Affairs, Ford Motor Company, quoted in "NCMS Focuses on Industry/Academic Collaboration," *NCMS, FOCUS*, September 1991.

7 From the December 1991 issue of *FOCUS*, published by the National Center for Manufacturing Sciences, Michigan.

- In 1989, U.S. output per man-hour increased by only 2 percent in manufacturing, a drop of 60 percent from the 1983-84 peak.
- Every fifth person now hired by American industry is both illiterate and innumerate.

a. Manufacturing Technology

The strategy here is to develop tools and techniques that would lead to an improved human-machine interface for manufacturing workstations, work cells, flexible manufacturing centers, and flexible repair centers. The customers of this strategy would be both industry (defense and commercial) and the logistics centers. Under the new acquisition strategy being proposed now in DoD, the organic manufacturing capability should increase. Reduction in overall procurement and the lengthening of programs may result in the Services' doing more in-house manufacturing in addition to repair.[8]

The growing interest in this area can be seen in the ESPRIT project in Europe, which focused on a similar effort called human centered technology for computer integrated manufacturing.[9] This project provided approaches to man-machine interfaces, software integration, and human centered job design. The impetus for this project was the recent interest in manufacturing system design based on retaining skilled craftsmen on the shop floor, not totally replacing them with factory automation. This practice of maintaining humans in the manufacturing loop also makes the introduction of flexible manufacturing systems (FMS) easier for mid- and small-sized companies.

The growth in simulation and modeling of manufacturing systems over the past decade has been facilitated by the availability of simulation languages for the building and analyzing manufacturing models. The need to improve manufacturing operations and assess the effect of decisions before implementation drove this growth in simulation and modeling. Recent advances have also recognized that the manufacturing system must include the interrelationships among the physical manufacturing environment, the manufacturing management, and the worker. This idea reverses the traditional Tayloristic

8 U.S. Congress, Office of Technology Assessment, *Redesigning Defense*.

9 Husband, T.M., "Human-Centered Technology for CIM Systems," Mechanical Engineering Department, Imperial College, London, United Kingdom.

approach where manufacturing practice occurs in a vacuum, "without regard to human factors."[10]

The Acquisition Logistics R&D Activity has extensive expertise in developing man-models and human performance models and in getting them tested by industry. Although the lab has not been closely tied to the manufacturing community in the past, it has been successful in the concurrent engineering community. And often, technology developed for one specialty engineering function in a concurrent engineering team can easily be transferred for use by another. There is a close tie between maintainability and producibility just as there is between the processes of maintenance/repair/overhaul and production. If the lab can work closely with the MANTECH office, which it should because of its proximity, and take advantage of manufacturing expertise through consortia, the current lack of manufacturing experts within the lab should not be a barrier to implementation of this strategy. It is the human factors expertise, which the lab possesses, that the manufacturing community needs now.

The DoD *Critical Technologies Plan* of 1 May 1991 includes Flexible Manufacturing as one of the critical technologies. One of the milestones of the Science and Technology (S&T) Program under the heading of CAD/CAM/CAE/CAPP (Computer-Aided Process Planning) is to develop "technologies for improving man-machine interfaces" targeted for fiscal year (FY) 1995. The Acquisition Logistics R&D Activity is in a position to get a fast start on this development.

Products from this effort would include research reports, manufacturing technology design recommendations, and training recommendations. Models for design influence on manufacturing technology and for early training documentation at the soft prototyping stage would be developed on the order of Crew Chief; Design Evaluation for Personnel, Training, and Human Factors (DEPTH); and Operability Assessment System for Integrated Simultaneous Engineering (OASIS). Human models needed to interface with the manufacturing equipment would have more of an operator than a maintainer function and would require anthropomorphic, ergonomic, and cognitive simulation.

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10 Joseph A. Heim and W. Dale Compton, eds., *Manufacturing Systems—Foundations of World-Class Practice*, Committee on Foundations of Manufacturing, National Academy of Engineering, National Academy Press, Washington, DC, 1992.

Taylor, of course is Frederick Winslow Taylor, who fashioned the modern manufacturing organization with his concepts of optimization of individual job functions, separation of thinking from doing, and "disregard of the human side of the enterprise."

b. Human Issues in Manufacturing Technology Insertion

The strategy here is to develop a methodology or technologies to assess the potential human impact of new manufacturing technology on the shop floor and to devise human centered process planning for ultimate safety of the work force.

> The competitive position of U.S. manufacturing and service industries in world markets has been of growing concern to managers, scholars, and policy makers since the 1970s. As has always been true when greater efficiency and higher productivity are desired, managers have turned to new, sophisticated workplace technologies. New technologies, however, have not proved to be a panacea for all the problems of productivity. . . . [There is an] increasing awareness among mangers and researchers that solutions to fading competitive ability cannot be found in a mythical black box of technology. In fact, any important technology has profound human consequences, both positive and negative, which often remain unplanned or unanticipated. Consequently, it is often the organizational and human factors that either facilitate or constrain the ability of firms and coworkers to adopt and implement new technologies.[11]

While the previous strategy is concerned with optimizing the design of manufacturing technology with respect to the human operator/machine interface, this strategy is concerned with the implementation of the technology on the shop floor and the optimal design of the manufacturing organization and its processes with respect to the human factors of the work force.

Part of the solution to some of the technology insertion problems lies in training; however, recent statistics on the amount of training needed and its cost to industry are not encouraging:[12]

- Noncollege graduates will fill 70 percent of nation's jobs in the year 2000.
- Most new employees will come from demographic groups traditionally having even fewer skills.
- Industry spends billions of dollars on training each year, but hardly any of that investment is for the kind of basic skills most needed by the noncollege graduates.

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11 So begins the preface of *People and Technology in the Workplace*, National Academy of Engineering and the Commission on Behavioral and Social Sciences and Education, the National Research Council, National Academy Press, Washington, DC, 1991. The realizations contained in this quote prompted the National Academy to address these issues in a symposium on 13-14 March 1989. This reference contains the results of the symposium, including several case studies from industry.

12 $200 billion total, $30 million in remedial education.

Training itself then becomes part of the problem, and fixing it requires a complete overhaul of the structure of many production jobs, an effort called process management by Motorola.[13] Process management involves streamlining and doing away with time-wasting jobs.

The customers of this strategy are ultimately all of the industrial base. Customers in the mid- and small-sized businesses can be reached by joining the Technology Transfer Consortia and using the Cooperative Research and Development Agreements (CRDA). The following are technology transfer interfaces that the Wright Research and Development Center (WRDC) has used:

- Ohio Science and Technology Council[14]
- Ohio Advances Technology Center[15]
- Dayton Area Technology Network
- Ohio Technology Transfer Organization (OTTO)
- Federal Laboratory Consortium[16]

Additional customers include the logistics centers. The process planning, pre-production, and production planning functions are all customers of this R&D strategy.[17] Workflow and facility layout design and assembly or job design with an emphasis on safety and the handling of hazardous materials are ideal opportunities for HCT implementation.[18] Although ALCs are huge organizations, there does not seem to be enough of this kind of activity at present at the ALCs. Hence, this strategy may be viable for the Acquisition logistics R&D Activity only in the near term if industry is also a customer. This situation may be expected to change in the future as the ALCs pick up more of the manufacturing function in the modernization of weapon systems and strive to

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13 "Corporations Get in the Business of Education," *NCMS FOCUS*, August 1991.

14 A 17 May 1990 report to Governor Celeste made recommendations in the following 5 areas: technology trends, research infrastructure, technology transfer and commercialization, human resources, and science and technology policy.

15 AFHRL was a member.

16 Midwest Regional Coordinator is the Office of Research and Technology Application (ORTA), WPAFB.

17 Predominantly found in the Engineering and Planning Branches of the Product Directorates at the ALCs.

18 CAD is being used in the ALCs for these purposes more so than for design purposes.

become more efficient. Again, an impediment to the implementation of this strategy could be the lack of manufacturing expertise in the lab.

Products include types of models such as Crew Chief, DEPTH, and OASIS that can be integrated with process models. Incorporation of hazardous materials (HAZMAT) handling and occupational safety considerations into a DEPTH-type model is very relevant for the ALC's process planning. For workflow planning, a simple model may be all that is required. For example, Computer-Assisted Design and Drafting (CADD) software is used by NASA's Goddard Space Flight center in Greenbelt, MD, for the shop sketches; people there say that there is little need for 3-dimensions, solid modeling, engineering analysis, or other sophisticated features.[19]

2. Multi-Level Tools for System Design

The strategy here is to develop a multi-level HCT tool for use on various machines, at various stages in the design, at different levels of management. The rationale is that although detailed HCT tools are required for complete human/machine interface issues and the other human factor areas of concern, a less complex tool would be useful for conceptual design or for managers who need only a top-level view. Management needs a quick, high-level assessment without the detail required by designers. The customer base is widespread, including industry, the System Project Offices (SPOs), and the Air Logistics Centers (ALCs). Because of the resident expertise in the Acquisition Logistics R&D Activity from developing fairly complex models (e.g., Crew Chief) and getting them tested in industry, we believe that this strategy can build upon the Activity's strengths.

Although some may argue that the boundaries between the two technologies are blurred, we believe that HCT efforts should begin to be tied to solid modeling as well as computer-aided design. As discussed in Chapter IV, solid modeling allows analysis to be done much earlier than traditional CAD and provides the following capabilities.

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19 "Goddard Space Flight Center Uses CADD to Launch Time-Saving Fabrication System," *SCAE Network*, October 1991.

> Solids modeling systems enable engineers to build, in a matter of hours, 3-dimensional models that allow accurate determination of mass properties, component interferences, and other key design characteristics in a matter of minutes. They reduce time significantly and allow more iterations. Models of subassemblies (e.g., sensors, circuit boards, power supplies) can be quickly constructed to allow the designer to arrange them in various configurations to find an arrangement that fits the available space. The design engineers can now build conceptual models themselves.[20]

Such a strategy would allow HCT to move into earlier phases of the design, and the earlier HCT analysis can be done in the design cycle, the greater emphasis it will have and the greater its ability to influence life cycle costs.

The product of this strategy would be a suite of computer tools. The upper-level tool would provide fast checks and highlight problems that the more detailed technology in a system such as DEPTH would integrate at a second level. A third level could be a human factors design checker to integrate with DEPTH and provide an automatic design checking capability.

3. Logistics Support Analysis Process

The strategy here is to provide HCT for the Logistics Support Analysis (LSA) process. This entails the development and use of a tool such as DEPTH to be used in a design documentation mode for the Logistics Support Analysis Record (LSAR). Direct customers would be the defense industry and the SPOs, but an indirect customer is also the ALCs. They need to use the LSAR documentation but find it worthless to them in the way it is produced at present.[21] The whole LSA/LSAR process seems to be in need of help. If LSA could be done properly under the authority of the SPO, it would not need to be redone at the ALCs. All research and development for this strategy should be carefully aligned with the CALS information architecture.

4. Repair Validation and Verification Process

The repair validation and verification process is an iterative, time-consuming effort between industry (validation) and the ALCs (verification). Currently, it is done by real

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20 "Advanced Solids Modeler Speeds Honeywell's Inertial Navigation System Design," *SCAE Network*, January 1992.

21 Part of the problem, for which GST may be a solution, is that the right people aren't involved in the process—the ALCs are basically left out.

people on a real (physical) prototype. This alternative strategy would be to research and develop HCT for this process in a simulated or modeled environment, making use of the human models and the virtual (electronic) mock-up of the system. As a long-term strategy the Acquisition Logistics R&D Activity should consider a virtual reality system as an alternative to the human model. The user of the virtual reality system would be a real repair person.

In either way, sufficient detail would need to be incorporated into the model. For flight line maintenance evaluation, additional capabilities that could be incorporated in the human models include the following:

- The effects of adverse conditions
- Modeling of the senses
- The effects of fatigue and errors
- The effects of gravity
- Strength modeling.

C. GROUP SUPPORT TECHNOLOGY OPPORTUNITIES AND STRATEGIES[22]

The people issues in GST, i.e., the decision-making or problem-solving aspects, not the distributed communications issues or the computer issues in document sharing, provide the best general opportunities for GST R&D by the Acquisition Logistics R&D Activity. This approach has the advantage of accenting the human factor, behavioral, and psychological expertise in the lab without having to rely on the computer or communications developments. There seem to be enough researchers emphasizing the computer aspects of GST, in some cases to the exclusion of the idea that the technology solution may not be the best solution for each group problem.

1. GST for AFMC

The strategy here is to develop a research program for GST which would support the many team meetings involved with the AFMC. Several types of meetings are available to study: strategic planning meetings at ASD; Process Action Team (PAT), natural work group, and quality circle meetings in the TQM program throughout AFMC; and program

[22] We were told by a reviewer that if the Joint Logistics Systems Center (JLSC) develops as currently planned, it will be the major customer for GST. Although not covered in the strategies listed here, it is a development that the Acquisition Logistics R&D activity should monitor closely.

reviews or requirements generation meetings in the SPOs. AFMC is a rich research environment because of the large number of meetings and the diversity of the groups holding them.

The first step in the strategy is to unobtrusively observe the teams and determine the dimensions of the types of meetings they hold. Different researchers in the field have identified different types of support required for different groups, but since no complete group taxonomy has been identified or agreed to in the research community, there is no consensus. Perhaps one of the first tasks of implementing this strategy would be to conduct a workshop—better yet, a GSS session—with the GST research community in order to develop some consensus on these issues and have a better definition of user requirements.

Once the foundation for this strategy is laid and the types of technology that may be beneficial for each type of team is established, the teams can be introduced to various forms of computer support for which trust has been established during the first phase of the strategy, and GST tools specific to Air Force requirements may be developed. The introduction of the computer is probably best done at a group support system (GSS) testbed facility in the lab where the participants' reaction to and satisfaction with the particular GST can be easily observed and recorded. A portable capability, on the other hand, may encourage greater use because of the relatively greater ease of introducing technology into a group's home environment. At this stage it will be important for the Acquisition Logistics R&D Activity to have trained facilitators for the group meetings if the meeting usually functions without one (all TQM group meetings should be functioning with a facilitator). If the group already has a facilitator, then only a technographer to operate the GSS and provide any necessary training will be required.

It is our experience that the first question we receive when proposing a group support system for a meeting is "Do you use it yourself?" The Acquisition Logistics R&D Activity will have a difficult time selling a GSS unless they themselves use it for their decision-making or problem-solving meetings. If they do and are happy with the results, the word will spread and just scheduling the use of the GSS facility or portable system will become a full-time job.[23]

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23 We have seen this happen with the Fusion Center at Ft. Belvoir, VA.

The products of this strategy would be technical reports in the beginning and software tools in the future.

2. Human Issues in Technology Insertion—Videoconferencing

The strategy here is to provide answers to the human issues in the adoption of and the efficient and effective use of videoconferencing technology. This strategy is very different from human issues in the manufacturing domain in that the manufacturing domain contains many simulations and models with which to interface an actual tool. This strategy involves taking a current technology, i.e., videoconferencing, and making it more compatible for human use.

Implementing this strategy would involve conducting research using the videoconferencing facility at WPAFB and observing, recording, and eventually conducting experiments with the various users of the facility. Products would be technical reports and formal methods or techniques that make this technology palatable.

In view of the reduced budget for travel and the current emphasis on involving all the key players for IPD and IWSM, videoconferencing will necessarily play a key part in product development. Videoconferences between the SPOs, the ALCs, and industry will occur more and more often until the high cost of distributed computer conferencing can be alleviated. Videoconferences are also held for TQM meetings between Commands. Customers of this strategy thus include multi-enterprise concurrent engineering or integrated product development teams, AFMC TQM teams, and ASD IWSM teams. The primary customer may be the ALCs, however, because of their need for videoconferencing and overt resistance to using it. This support could help the ailing LSA/LSAR process as well.

3. Integrated Weapon System Management Process

This strategy involves researching the integrated weapon system management process and developing tools and techniques to aid the decision control in the group processes. The customer is the AFMC, specifically the SPOs and the ALCs; because of the way IWSM will be structured, the SPOs and the ALCs have similar responsibilities at different levels and times. According to a recent white paper signed off by the Commanding Generals of both AFSC and AFLC, the single-face-to-the-user concept will be implemented in the following way:

> A single organization, the system program office, manages the weapon system or commodity. This organization is headed by a single individual, the system program director. . . . A system support manager from a logistics center will be assigned to the program office and will report to the system program director. System program directors for commodities will be located at the logistics centers, will have a product focus, and will call upon the product centers for assistance in commodity development programs. . . . A weapon system program office remains at the product center until weapon system development is complete. The office may relocate to a logistics center later in life when the predominate activity is operational support. [When fielded weapon systems face modifications with major development activity, lead management responsibilities may be relocated from the logistics center to a product center.][24]

This structure is convenient for the research activity because technology developed in this area for the SPOs, which can be locally studied, should also be applicable to the ALCs.

Since AFMC is a major organization and IWSM will greatly affect how the Air Force does business, finding a way to develop technology useful to the IWSM offers a significant opportunity to the Acquisition Logistics R&D Activity. Since AFMC headquarters and major program SPOs are located at WPAFB, some of the processes requiring GST should be easy to observe.

One of the specific and immediate customers of GST in the IWSM process may be the Center for Supportability and Technology Insertion,[25] Acquisition Modeling, (CSTI/AM) at WPAFB. The center's objective is to improve the acquisition process by providing SPOs, Program Executive Officers (PEOs), Service Acquisition Executives (SAEs), Product Centers, and Logistics Centers with information for planning, managing, and executing the program. Its immediate goal is to develop an acquisition model that captures the document preparation process. The Center's ultimate goal is to capture the IWSM process. This effort is receiving high-level attention by the Commanding General of AFSC (see Section II.C.1). Currently, the concept perceived by CSTI/AM is a single-user system, resident on individual personal computers (PCs). However, much of even the first phase of the model requires supporting the preparation of documents that require

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[24] *Integrated Weapon System Management in Air Force Materiel Command*, a white paper, 28 January 1992.

[25] This is the former Acquisition Logistics Division of the AFLC.

transfer and development among groups of people, not a single person. Thus the opportunity for groupware concepts to be incorporated into the Acquisition Model seems evident. The strategy here would be the cooperative research and development of a groupware capability for the acquisition model.

4. ALC Processes

The strategy here is to develop GST for the many group meetings and reviews required in the development and implementation of the repair/overhaul/manufacturing processes at the ALCs. The design of the production process at an ALC rivals in complexity the design of many products and requires many decisions among groups of people, in and out of meetings, at formal and informal reviews. Communication among the different branches and divisions at OC-ALC seemed to be a major problem; there is a need for better communication among the diverse groups. In our interviews, consultants and other people knowledgeable about ALCs likened them to monstrous bureaucratic institutions, much like the defunct Soviet Union. Personnel on both sides of the management/maintenance continuum at OC-ALC expressed the desire for reduced time spent "putting out fires." This may suggest that decisions are not being made properly by involving the right people to guarantee implementation.

The products of this effort would be group support tools and techniques that rely more on formal methods and facilitation than on the use of computers by every member of the group. In fact, the latter idea probably should not be broached until some success has been demonstrated with the formal methods and facilitation. There appears to be a great need for help in the decision-making and planning processes at the ALCs. Initial work could focus on providing technical reports that recommend specific methods or techniques for groups like those found at the ALCs. To do this, the dimensions of the different types of groups at the ALCs would need to be determined.

5. Concurrent Engineering[26]

The strategy here is to develop GST for use by concurrent engineering teams in meetings. A large market exists for this type of technology because concurrent engineering teams require face-to-face meetings almost daily. Geographically distributed meetings are also held among team members in multi-enterprise developments and with customers and suppliers (but with less frequency). Many techniques and tools used for decision making or problem solving in face-to-face meetings could be used for distributed meetings if applied properly.

Unlike the personnel at the ALCs, engineers in industry are adept at using computers; they frequently use computers for their individual decision support. In contrast to GST for ALCs, computer support for group problem solving in a concurrent engineering team will require integration with analysis tools used by individual team members and will probably need to have a strong graphics capability.

In addition to industry, the SPOs are also customers for this strategy. The SPOs will have concurrent engineering teams of their own, although they will not function in quite the same way as those in industry. The types of decisions made in the SPOs will differ from those in industry. One problem area for this strategy is that many of the processes of concurrent engineering are product specific and most are company specific. Generic processes for decision support may be difficult to define because each company is rapidly developing its own techniques.

One of the strengths of this strategy for the Acquisition Logistics R&D Activity is all of its prior work in engineering design,[27] Unified Life Cycle Engineering, and concurrent engineering and its recognition in the field of concurrent engineering. Previous work such as RAMCAD, however, has concentrated on analysis tools for a specialty engineering function. User requirements are much easier to define for such a tool than for a process involving players from all the engineering functions.

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26 Additional information on this topic can be found in two papers previously published by IDA and supported by the Acquisition Logistics R&D Activity: David A. Dierolf and Karen J. Richter, *Computer-Aided Group Problem Solving for Unified Life Cycle Engineering (ULCE)*, IDA Paper P-2149, February 1989; and David A. Dierolf and Karen J. Richter, *Concurrent Engineering Teams*, IDA Paper P-2516, Volume I: Main Text, and Volume II: Annotated Bibliography, November 1990.

27 Some of the systems design work of Gerald Nadler, co-chair of the symposium planning committee for *People and Technology in the Workplace*, was discussed in *A Survey of Research Methods to Study Design*, IDA Paper P-2155, which was supported by the Air Force Human Resources Laboratory.

Because a generic all-purpose GSS for concurrent engineering may be difficult to define, developers of specific strategies and products should—

- Publish technical reports on the dimensions of concurrent engineering group decision making and problem solving with recommendations for appropriate tools.
- Develop an expert-system type advisor to help a concurrent engineering team to choose correct GSS tools at appropriate times.
- Develop a design decision capture tool for use in concurrent engineering team meetings.
- Develop and publish interface requirements that allow lessons learned data bases to be used in a group setting.
- Develop and publish interface requirements for the formal methods in TQM [e.g., Quality Function Deployment (QFD)] to be used in a group setting by a concurrent engineering team.

An example of research in this area, which may be pertinent to any involvement of the lab with the CERC, is being conducted by Tang and Leifer[28] under funding from Xerox Palo Alto Research Center (PARC), which also provided the research environment in the Intelligent Systems Laboratory.[29] In Tang and Leifer's research to guide the design of tools to support group design activity, they have determined the importance of hand gestures. If the hand gestures are not perceived by the other members of the group, problems can arise. The lack of perception can be caused by distraction, such as in a meeting with many participants or in computer-augmented rooms that are cluttered with computer equipment, e.g., Colab. Meetings in which participants reside in physically remote regions create particular problems in this area. Tang and Minneman have developed a prototype tool called VideoDraw that "uses video to convey hand gestures in support of collaborative drawing activity."[30]

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28 John C. Tang and Larry J. Leifer, "An Observational Methodology for Studying Group Design Activity," *Research in Engineering Design*, Volume 2, 1991, pp. 209-219.

29 Xerox PARC developed Cognoter, a group support program to be used in the Colab, an experimental laboratory to study computer support of cooperative real-time group problem solving. (Mark Stefic, Gregg Foster, Daniel Bobrow, Kenneth Kahn, Stan Lanning, and Luch Suchman, "Beyond the chalkboard: Computer Support for Collaboration and Problem Solving in Meetings," *Communications of the ACM*, Vol. 30, No. 1, January 1987.)

30 John C. Tang and Scott L. Minneman, "VideoDraw: A Video Interface for Collaborative Drawing," *Proceedings of the Conference on Computer and Human Interaction (CHI) '90*, Seattle WA, April 1990, pp. 313-320.

D. SUMMARY

The strategies presented in this chapter are results of a front-end analysis concentrating on customer requirements. It is important that the Acquisition Logistics R&D Activity involve the customers in determining the requirements for future research and development. Strategic planning should be an ongoing process instituted in the Acquisition Logistics R&D Activity to focus on customers requirements. They have made a commendable effort so far, and continuing efforts in this area will ensure that their work receives the widest dissemination possible.

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